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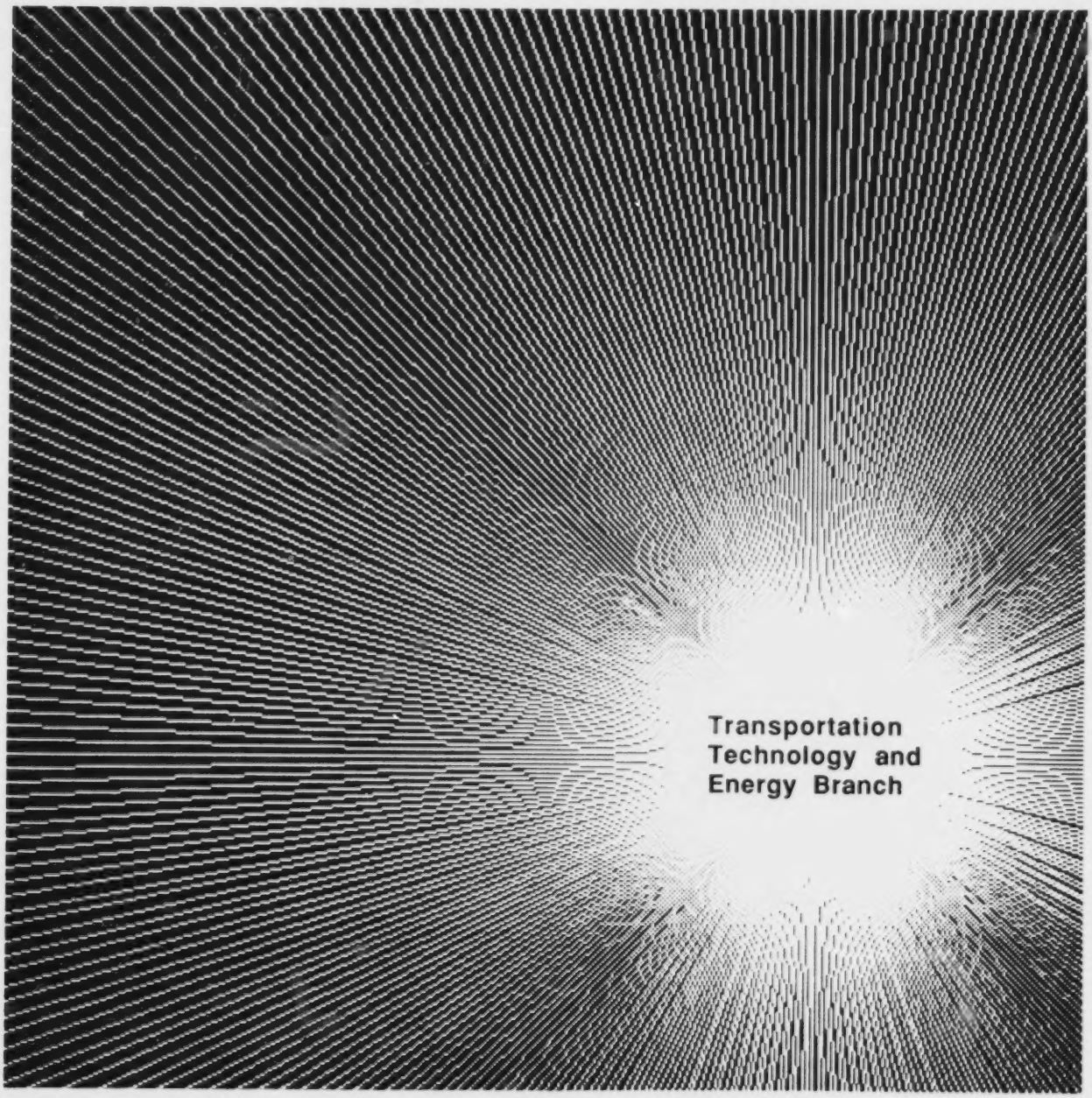

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Automatic Vehicle Location and Control Systems for Small and Medium Ontario Transit Properties: Phase 1 Report (Final)

TCT-91-02

Technical Report Documentation Page

Automatic Vehicle Location and Control Systems for Small and Medium Ontario Transit Properties: Phase 1 Report (Final)

Prepared by: **B. Pekilis, P. Eng.** and **G. Heti, P. Eng.**

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Abstract: This report results from a study initiated by several Ontario transit properties, together with the Ministry of Transportation of Ontario (MTO) and the Canadian Urban Transit Association (CUTA). The report assesses Automatic Vehicle Location and Control (AVLC) systems, and their associated technologies, for small and medium Ontario transit properties.

The purpose of the report is to provide the background information necessary for the creation of a functional specification in preparation for a series of AVLC demonstration projects at several participating Ontario transit properties. The aim is to develop a province-wide standard that will meet the needs of the majority of properties in Ontario.

During the course of this study, user requirements were identified through a survey of participating transit properties. The survey indicates that the introduction of AVLC systems in Ontario will significantly impact a property's operational and management practices. Also identified are essential, desirable, and optional system requirements. These two areas will form the basis for the development of an AVLC functional specification for Ontario.

Key words: Automatic vehicle location and control systems, Transit operations, Driver communications, Land-based radio location systems, Satellite-based radio location systems, Signpost/odometer-based systems

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Automatic Vehicle Location and Control Systems for Small and Medium Ontario Transit Properties: Phase 1 Report (Final)

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PREFACE

The research, data collection, and preparation for the first release of this report was conducted by the authors from September 1990 to October 1991. Additional editing and updating for this final release was performed from November 1991 to January 1992.

The report, and the project from which it originates, were commissioned by the *AVLC for Small Ontario Properties Steering Committee*, a project group consisting of members from the Ministry of Transportation of Ontario, the Canadian Urban Transit Association, and six Ontario transit properties.

This is the second and final release of this report. The first release was sent to all those who participated in the study and the data collection phase. In all, some 70 organizations and people received first release copies. Readers' comments, suggestions, and notable corrections were solicited.

The authors would like to take this opportunity to thank those who graciously responded to the first release, freely providing their opinions and suggestions. Most of what was received has been incorporated into this final release.

Most of the changes made to the report were in three main areas. The first was the pricing of the various location technologies, most notably the drastic reduction in the cost of GPS receiver technology. The second was the addition of several new figures and tables. The third area involved changes in the vendor descriptions which were dated in some cases and required updating. Again, thank you to those vendors who assisted us in ensuring that their descriptions were accurate. The result has been mutually beneficial.

This past November, the first release of the report was presented at a full meeting of the AVLC steering committee. The report was reviewed and then used as a basis for discussion. The meeting, ideally comprised of individuals from both transit and government, provided an excellent forum for the presentation and discussion of new ideas and principles. The committee established several objectives of AVLC for small- and medium-sized Ontario properties specifically, and all transit properties in general.

At present, the primary issue facing smaller transit properties interested in adopting AVLC for their operations is **affordability.** This appears to be an issue related to restrained capital and operating budgets and current economic conditions.

The committee also attempted to identify main AVLC objectives that smaller properties should focus on. There were several, but the ones listed below were chosen as the four that could best be measured in qualitative terms:

1) improved service **reliability**
2) greater operator and public **security**
3) better and more timely **public information**
4) **guaranteed transfers** at specified points

The committee believes that the opportunity also exists for properties to use AVLC to fine tune their systems in an attempt to reduce and control overall operating costs.

We are pleased to report that the practical aspects of the report's conclusions and recommendations were unanimously approved by the steering committee. As a result, the committee further agreed that the next phase of the AVLC project should commence. Phase II has begun and involves the creation of a generic AVLC system bid document package which will contain, at minimum, the following:

- a section providing generic functional specifications for a transit oriented AVL system providing basic capabilities such as vehicle location and tracking;

- a section providing generic functional specifications for a transit oriented AVLC system providing additional capabilities such as schedule adherence monitoring, real-time fleet control/dispatching, and historical database management;

- a section providing generic requirements typically supplied by transit properties tendering for AVL or AVLC systems;

- a section providing any specialized contractual terms or conditions for the procurement and installation of an AVL or AVLC system by a transit property over and above those generally used by Ontario municipalities;

- a property-specific section, in the form of a series of appendices, providing individual transit property information on items such as management practices, site of fleet, type and capability of radio system and computer hardware, and available databases.

It is hoped that the package will assist the province in bringing about AVL/C standardization in two ways:

- first, by creating a set list of AVL/C system functions from which properties will be able to choose;

- second, by standardizing certain technical specifications to ensure systems can be installed anywhere without the need for major redesign, redevelopment, and system test work.

If these goals are achieved and an appropriate system demonstrated, an AVL/C standard will be created and then adopted throughout Ontario.

There is also an advantage in standardizing central software and database requirements, central-to-vehicle communication protocols, and onboard vehicle hardware architecture. This again will help to end the cycle of continuously debugging and redesigning major AVL/C system subsystems with new AVL/C system procurement and installation.

The committee hopes to demonstrate the following systems:

- an AVLC-type system for conventional fixed-route transit
- an AVL-type system for conventional fixed-route transit
- an AVL-type system for demand-responsive transit.

However, the ultimate decision to proceed will depend on the successful completion of Phase II of the AVLC project, the availability of funding resources, and the identification of one or more suitable demonstration sites.

Future reports will be made available as appropriate.

EXECUTIVE SUMMARY

This report results from a study initiated by several Ontario transit properties, together with the Ministry of Transportation of Ontario (MTO) and the Canadian Urban Transit Association (CUTA). The report assesses Automatic Vehicle Location and Control (AVLC) systems, and their associated technologies, for small and medium Ontario transit properties.

The purpose of the report is to provide the background information necessary for the creation of a functional specification in preparation for a series of AVLC demonstration projects at several participating Ontario transit properties. The aim is to develop a province-wide standard that will meet the needs of the majority of properties in Ontario.

The goals of standardization are to:

- lower overall AVLC system development, procurement, and installation costs;
- share in the know-how and operational experiences of Ontario transit properties;
- gain experience and insight into the operational benefits of AVLC systems;
- attempt to boost Canadian AVLC system suppliers (where applicable).

During the course of this study, user requirements were identified through a survey of participating transit properties. The survey indicates that the introduction of AVLC systems in Ontario will significantly impact a property's operational and management practices. Also identified are some essential, desirable, and optional system requirements. These two areas will form the basis for the development of a AVLC functional specification for Ontario.

The report details its conclusions and recommendations in the following areas:

•Provincial AVLC System Standardization,
•Location System Technology,
•AVLC-related Computer Hardware and Software,
•AVLC System Implementation Methodology,
•Transit Property Operational and Organizational Impact,
•Grouping Ontario Properties Based on AVLC Requirements,
•Additional Recommendations.

The following are highlights of the recommendations of this report:

•A functional AVLC standard for the Province of Ontario should be developed.

• MTO should encourage provincial AVLC system standardization through the use of a joint procurement strategy (JPS).

•Small and medium transit properties should **not** engage in custom development projects to implement their AVLC systems.

•MTO should continue to work with Ontario transit properties to study control strategies and methods used to monitor and control their fleets.

• MTO, CUTA, and the AVLC Steering Committee should encourage the formation of an Ontario Transit Automation, Innovation, and Technology (OTAIT) user's group.

•Transit properties should consider tying their paratransit operation into an AVL system.

The following are highlights of the conclusions of this report:

•The technology exists that would allow MTO to conduct AVLC demonstration projects at one or more Ontario transit properties.

•The North American AVLC marketplace is presently in a state of flux.

•No one individual location technology is currently sufficient to meet all the tracking and accuracy requirements of a transit AVLC system.

•The type of central site computer hardware will depend on the size of the transit property, the desired level of departmental automation, and the type of software applications required throughout the property.

•The core of a transit property's AVLC system is the associated databases.

•The roles of the various transit property organizations and departments will be impacted by the introduction of AVLC.

•Ontario transit properties belong to one of two groups: those properties requiring full AVLC systems and those properties requiring location-only AVL systems.

•The major challenge for Ontario transit properties in the 1990s will increasingly focus on the training and motivation of their employees as new innovations are integrated into the transit industry.

1/ INTRODUCTION

Ontario transit system operators presently face the challenge of improving service and safety while trying to accommodate staff, passengers, and funding agencies. This challenge must be met in an environment of traffic congestion, stagnant ridership, and constrained budgets. Ontario's transit properties, in following worldwide public transit trends, need specific technological answers to help them meet their short- and long-term goals.

Enter AVLC systems. Today's generation of automatic vehicle location and control (AVLC) systems combine:

- vehicle positioning technology and location information
- computer hardware, software, and graphics
- database storage and management
- digital communications
- other electronic systems.

AVLC systems give transit properties the tools they need to monitor and control their fleets. AVLC systems are applicable to fleets operating on fixed routes, in demand responsive roles, or a combination of both.

AVLC provides the transit operator with:

- up-to-the-second information on transit and paratransit vehicle locations
- real-time exception reporting of significant route/run schedule deviations
- real-time exception reporting of off-route vehicles
- remote emergency and mechanical alarm facilities
- real-time and off-line schedule adherence monitoring information
- historical data storage in shared databases
- additional dispatch and fleet management capabilities.

As attractive as implementing an AVLC system may be, it is not, however, without some obstacles. Recently alternative location technologies, systems, and suppliers have proliferated. New systems and suppliers continue to emerge on the scene; established systems and suppliers occasionally disappear. New technologies and the long-term impact of new product developments have, at times, made the transit AVLC marketplace difficult to assess. Difficulties also arise in deciding whether to purchase an off-the-shelf system or custom develop a solution from scratch.

The desire to benefit from, and the difficulties in the specification and procurement of AVLC systems has created a need within several of Ontario's small and medium transit properties. This need has prompted MTO, CUTA, and several Ontario municipal transit properties to begin a project that will define a broad set of common AVLC system requirements. The goal will be to specify and produce an AVLC system

standard, applicable to all Ontario transit properties, should this prove to be both desirable and possible.

To meet this end, a project team was established in 1989. The team presently consists of MTO and CUTA staff and transit property representatives from the Ontario municipalities of Windsor, Kitchener, Burlington, Brampton, Sudbury, and Peterborough.

The project team goals are to:

- organize on-site visits to view existing AVL and AVLC systems;
- assess AVLC's impact on the operations of transit properties;
- define the participating transit properties' operational and user needs;
- review available location technologies and AVL systems;
- develop a set of recommendations as to the best means of obtaining a low cost, standardized AVLC system, capable of meeting Ontario's small and medium transit properties' needs.

Therefore, the aim of this AVLC project is to define a set of functional system requirements for Ontario's small and medium transit properties. This will be considered Phase I.

Phase I, if successful, will be followed by the installation, testing, and general demonstration of one or more proposed AVLC systems, in one or more participating properties. This will be considered Phase II.

If the first two phases prove successful, the goal of Phase III will be to install, where applicable, the same or similar AVLC systems in transit properties across the province.

One final note about standardization. A move toward province-wide standardization does raise concerns about AVLC system feasibility, flexibility, and its true benefits. The major reason for striving to achieve a measure of standardization is to reduce development and implementation costs. Also important is the establishment of equipment standards to ensure that technical support and maintenance will be available down the road. On the other hand, standardization can also act to stifle new development and limit supplier innovation. This is not in anyone's interest.

2/ AVLC OVERVIEW

2.1/ Background

The application of AVLC systems to public transit operations has been accomplished in North America, Europe, the U.K., and Japan. The purpose of the properties' implementing these systems has been to furnish their staff, from management to the driver, with the tools necessary to:

•improve the safety and security of drivers, passengers, and the general public
•provide more reliable service to the public
•allow for more efficient transit resource management
•provide real-time schedule information to the public.

At the heart of any AVLC system is the ability to track a fleet of vehicles, and to monitor and record both predetermined and spontaneous events as they occur. The ability to locate vehicles and compare their passage, in terms of time and distance, with a master schedule, allows for:

•enhanced identification and handling of incidents and major delays as they occur;
•refined schedules that more closely reflect the true on-street travel times;
•on-going collection and storage of historical route travel time information by time of day, day of week, or season.

This collection, storage, and analysis of daily route/run data permits transit properties to develop schedules tailored for the period, season, road conditions, and location of a given service. More accurate and realistic schedules should lead to:

•better and more efficient allocation of transit fleet, staff, and management resources;
•reduce driver stress and frustration;
•greater public confidence in the reliability and level of service provided by the transit property for its riders.

If unexpected delays do occur, controllers and dispatchers can react more quickly to bring service back to normal. If a delay is unavoidable, transit users can be informed of schedule deviations before starting their trip. This public service will help to reduce unnecessary rider waiting times at departure, arrival, and transfer points.

Another benefit AVLC systems provide is a reduction of the necessary amount of voice radio communications between the driver and control. This allows the driver to concentrate more fully on his primary functions.

Controller awareness of headways and specific route/run information means that drivers are called by the central control only when driver action is required. A clear

picture of the overall transit system operation allows for fully informed controller decisions based on precise, reliable, and timely information.

Although AVLC systems offer transit properties many benefits, their cost and complexity can be high; the actual number of systems in North America is low. However, many AVLC systems are presently being developed and implemented. In Canada, systems have been installed in cities such as Halifax, Hamilton, Hull, and Toronto. In the United States, several systems are in operation, including those in Champaign-Urbana, San Antonio, and Sheboygan.

Across North America, AVLC systems are under proposal or in the process of being implemented. In the past, systems implemented generally have been complex and expensive one-of-a-kind custom developments. Presently, some lower cost, off-the-shelf packaged systems with known functional limitations do exist.

Cost comparisons between different AVLC systems are difficult because:

- the choice of location system will impact the cost of outfitting a fleet and the central site equipment;

- in-vehicle equipment variations may range from an installed minimum to complex location, data control, and communication systems;

- central site installations may range from sophisticated computer and communication systems, run in-house by the transit property to simple displays where the central control of a commercial fleet tracking company provides the data via land lines;

- the AVLC marketplace has not yet achieved maturity and still reflects competitive bidding between the various vendors and manufacturers based on their different prototype demonstrations and technological installations.

2.2/ Major Elements

AVLC system equipment can be divided into five major categories:

- onboard vehicle logic unit and driver control head;
- onboard vehicle location devices, sensors, and systems;
- vehicle and base station data and voice communications system(s);
- base station and central site host processor hardware and computer systems;
- AVLC system software.

Depending on the overall system requirements, the central hardware and software may be configured quite simply. Recent advances in microprocessor-based computer hardware have provided the marketplace with powerful, inexpensive workstations and personal computers. These computers can be used with networking technology,

providing an alternative to the mainframe or super-minicomputer approach to central computer control.

On the software side, systems can integrate shared relational databases, graphics, electronic mapping capabilities, and standard textual tables and lists. Enhanced software systems support database management, real-time map-matching, schedule analysis, route planning and design, automatic schedule generation, and an interface to passenger information systems.

Digital communication systems are straightforward and can support data, voice, or both. Existing voice radio systems are typically upgraded and used where possible to reduce costs. In addition, the continent-wide implementation of a backbone digital cellular network provides an alternative communications medium to conventional radio-based systems.

Onboard vehicle logic units (data control systems) and driver control heads range from:

- no onboard equipment
- a simple digital two-way voice radio system
- a computer-assisted two-way voice radio system
- a microcomputer and communications system, with Liquid Crystal Display (LCD) display and keyboard.

The need for other onboard vehicle equipment depends on the nature of the communication and location system employed and the desire to monitor other vehicle functions.

2.3/ Positioning and Location

One of the challenges of implementing an AVLC system is the selection of the vehicle location technology. Care must be taken because the nature of the location system impacts the cost, accuracy, expansion capability, functionality, and reliability of the system.

The choice of location system is further complicated by the number of new location technologies available in the marketplace. Alternatives range from the proven signpost- and signpost/odometer-based systems to newer, but still developing, dead-reckoning-based, and land- and satellite-based radio location systems.

Signpost/odometer-based location systems work well in fixed route applications but are generally impractical for demand responsive and hybrid operations. Signpost/odometer-based system costs are dependent on the density of the signposts required and the layout of the routes throughout the city, suburbs, or rural centres.

Dead-reckoning-based location systems can determine a vehicle's position relative to a starting point by tracking the distance and direction travelled. Systems may greatly suffer from drift over long distances and do require periodic calibration and location correction. For these reasons, dead-reckoning-based systems may operate with other location systems and may also include map-matching software to correct and eliminate tracking errors.

Land-based radio location systems have proven effective, but do experience problems with loss of location signals in built-up areas and near power lines and substations. However, once location signals have been re-acquired, systems automatically relocate the position of the vehicle.

Satellite-based radio location systems used to be the most expensive alternative. Within the past year, however, this has changed. Over time, these systems may prove to be less expensive and more reliable than other location systems. In built-up areas, where line-of-sight with location satellites can be obscured, problems similar to those of land-based radio systems, are experienced. However, once satellite contact is restored, the location of the vehicle is immediately known.

Both land- and satellite-based radio location systems can operate on a forward or reverse basis.

In the forward case, location signals are broadcast from multiple transmitters and a form of triangulation is used in the vehicle's receiver to determine its position. This position is then transmitted to a central site.

In the reverse approach, the central site polls the vehicle. When polled, the onboard equipment transmits a beacon. The beacon is then detected by multiple receivers (three or more) located throughout the service area. The central site system calculates the vehicle position using time delay information gathered when the beacon was received. With the reverse approach, there is no need for a separate communications channel for location information transmission to the central site.

3/ AVLC TECHNOLOGY

3.1/ AVLC Subsystems

The key elements of an AVLC system are the subsystems that provide communications, location monitoring, data transfer, and central site computer processing.

The data transfer subsystem is the backbone of the overall system. On the vehicle, it may consist of equipment to capture location, status, and event data, combined with a means of electronically transferring this information to a central location. Some systems send and receive data, both from the vehicle to the central site and vice versa, via one or more mobile radio channels.

The mobile radio channels are the same type of channels used for voice communications. To allow data transfer, it is converted to a signal that is compatible with the characteristics of the channel. This requires conversion of the data from a digital to an analog signal (i.e., data to voice) before transmission. This is the job of a modem.

The modem converts the digitally coded data message from a set of binary 1's and O's to the analog equivalent of sounds. After being sent to the central site, the sounds are then converted back to the original digital information. The same procedure is followed when the central site sends data to the vehicle's onboard data system.

Driver communications may be provided by the same mobile radio system used to transfer the data. In most systems, the radio is usually in the data-transmit-receive mode by default. When a driver desires a voice link with the central site, a request for voice communication via the data subsystem must be initiated. The data subsystem will place the radio into voice mode. At this point, the driver may use the two-way radio to talk with the central site. When voice communication is complete, the data subsystem automatically places the radio back into data mode.

Location registration equipment depends on the type of AVLC system implemented. If the system is signpost/odometer-based, a special receiver is usually required on each vehicle to detect the beacon signals encountered along the route. Land- or satellite-based systems require the installation of a receiver or transponder on the vehicle. This equipment is designed to receive or send the signals used in determining the vehicle's location. If a dead-reckoning-based system is implemented, the equipment to calculate the relative location of the vehicle is necessary.

At the central site, the host computer can be almost any size, from a desktop to a mainframe system. System size is determined by the scope of the AVLC system and the extent it will be integrated into the transit property's entire information system. For a large transit property, several remote sites may be used to collect data from transit vehicles in their sector. These base stations may pass through data bi-directionally between vehicles and the central site. The link between the base stations and the

central site is typically via conventional telephone data links, although microwave radio links have also been used by some properties.

3.2/ Location Systems

The subsections that follow provide the basis for discussion of the major classes of location systems available. In addition to some basic technical background, the advantages and disadvantages of each type of system are also discussed. The subsections, however, are not intended to cover every possible type of location technology available in the marketplace, providing instead a general overview. The types of location systems covered in this study are:

Signpost/Odometer-Based Systems
- proximity signpost (wide and narrow area)
- reverse proximity signpost

Dead-Reckoning-Based Systems
- with map-matching

Land-Based Radio Navigation Systems
- LORAN-C (forward)
- Omega (forward)
- reverse approach

Satellite-Based Radio Navigation Systems
- Global Positioning System (forward)
- Geostar (reverse)

Signpost-based systems can be configured to operate in a forward or reverse mode. In either case, the cost of the infrastructure of roadside equipment is usually borne by the transit property or the associated municipality.

- In the forward approach, the onboard vehicle system requires a special receiver to detect independently operating beacons. Each beacon or signpost transmits a unique ID code. The communication of vehicle and beacon location information to the central site is performed by the onboard system.

- In the reverse approach, the onboard vehicle system may be as simple as an inexpensive passive electronic tag or transponder. The wayside equipment, however, requires an antenna, RF module, and expensive reader system to detect the passing of the vehicle. Each wayside reader system must be connected to the central site, also at additional cost.

Dead-reckoning-based systems can range from simple odometer/compass arrangements to complex, sophisticated, and costly gyroscope and accelerator systems.

These systems also require an onboard data system to calculate and maintain the relative position of the vehicle. All dead-reckoning-based systems suffer from accumulated tracking errors and require the additional cost of error correction facilities. These facilities may be as simple as a driver reset button on the data unit or the addition of a signpost- or radio-based location system to periodically reinitialize the system. All costs, regardless of the type of reckoning used, will be borne by the transit property.

Radio-based location systems, whether forward or reverse, have one major advantage over the other systems discussed so far: the cost of the infrastructure is typically NOT borne by the transit property or municipality.

- In the forward approach, the land- or satellite-based transmitters are typically supplied and maintained by national governments. Each vehicle is fitted with a sophisticated radio-location receiver and a data communications system. Vehicle position is determined either onboard or at the central site.

- In the reverse approach, the vehicle contains a simple low-cost transponder. A private company typically provides the communications and location infrastructure. The vehicle position is calculated at the company's central control facilities and then sent to the client sites over land-lines. Normally, a monthly usage fee is charge by the company in addition to the initial transponder purchase.

3.2.1/ Signpost/Odometer-Based Systems

The conventional forward approach to a signpost-based systems uses a series of proximity signposts to get a very accurate geographical position fix. Signpost/odometer-based systems use the vehicle's odometer to monitor the distance travelled by the vehicle between signposts. Located at the wayside (i.e., on street poles), the signpost emits a beacon which can be detected by any vehicle fitted with the proper receiver.

Each signpost has its own distinct code or ID. When a vehicle's signpost receiver receives a signpost ID, it transmits this information over the data/voice radio to the central site system. The central site system can determine which signpost the vehicle passed and, hence, the vehicle's location using the signpost ID.

There are two types of signpost beacons available. Narrow focus beacons (i.e., 15-metre radius) transmit their ID code over a tightly defined area giving a fairly accurate location within the coverage zone. Wide focus beacons (i.e., 60-metre radius or more) cover a wider area. Generally, narrow focus beacons are more accurate. However, a wide focus signpost may be used to cover several routes within its vicinity, and software can be used to correct inaccuracies.

The main drawback to a purely signpost-based system is that the position of the vehicle is only accurately known to within 300 to 360 metres (based on 150- to 180-

metre block lengths and two-block signpost spacing). Therefore, to improve the location accuracy without increasing the signpost density in a given service area, the vehicle's odometer is monitored. This provides an approximate distance travelled by the vehicle between signposts. The odometer produces electrical pulses that represent the distance travelled. In some cases, 64 pulses are produced per wheel revolution. In other cases, a pulse might only occur every three metres. Either way, with proper calibration, the distance the vehicle travels between signposts can effectively be monitored.

In addition, because the central site computer can periodically locate the vehicle very precisely (i.e., at a signpost), any inherent odometer inaccuracies can be corrected for at that time. In general, accuracies of 15 metres to 150 metres in existing property installations have depended on the density or number of signposts in the service area. This signpost/odometer approach is used by the Toronto Transit Commission (TTC) for its Communications Information System (CIS).

Another possible signpost application includes the inverse or reverse signpost approach. In this type of system, the vehicle contains a transponder or transmitter and the distributed roadside signposts act as receivers or readers. Each signpost is typically connected via land-lines to a central site for data collection and processing. Ottawa-Carleton Regional Transit Commission (OC Transpo) is in the prototype demonstration phase of a tag-based reverse signpost system.

OC Transpo has mounted low-cost passive transponder tags on the roof of all its vehicles. Six wayside readers have been strategically distributed along a Transitway to collect vehicle location information for the central site. As a vehicle passes under the wayside reader, the reader's transmitted signal is received and reflected back by the tag. The tag modulates the incoming signal, adds information such as the vehicle number and reflects the signal back to the wayside reader. This system does not use odometer information when determining vehicle locations.

Another alternative is the use of embedded loops in the pavement instead of wayside readers. This method has been used in the Netherlands, Canada, and the United States. Also, in France, a door-opening sensor is used to calibrate the vehicle's position at each stop instead of an odometer. The bus can then calculate its position from the start of each route.

Estimated Costs

Low-power proximity signpost beacons are low-cost, self-contained units. Battery power technology has removed the need for connection to an electrical supply and allows units to operate for up to five years without attention. Chargable batteries allow signposts to tap into street lighting supplies, charging at night and using batteries during the day.

The location system configuration for a standard forward signpost/odometer-based system typically consists of a series of strategically placed signposts (beacons) along fixed routes. Each vehicle in the fleet is equipped with a signpost receiver, antenna, and odometer interface. The approximate costs on a per vehicle and per signpost basis are shown below.

Approximate Costs: Forward Signpost-Based System

Receiver	$ 240
Odometer Interface	$ 50
Total Onboard Equipment per Vehicle	**$ 350**
Wayside Proximity Signpost Transmitter per Location (Plus Installation)	**$ 500**

The location system configuration for a typical reverse signpost system consists of a series of strategically placed wayside reader stations (reader, RF modulator, antenna) along fixed routes. Each vehicle in the fleet is fitted with an electronic tag. The approximate costs on a per vehicle and per reader basis are shown below.

Approximate Costs: Reverse Signpost-Based System

Passive Electronic Tag (transponder)	**$ 50**
Wayside Reader	$11 000
RF Modulator	$ 2 500
Wayside Antenna	$ 1 000
Total Wayside Equipment (one antenna per reader)	**$14500**

Note that the approximate costs listed here **exclude** the costs of the central control computer and communications equipment. Also not included is the cost of installation of the wayside equipment. Each signpost in a forward system must be installed. Each wayside reader in a reverse system must be also installed, but there is the additional cost of a weather-proof cabinet and cabling for the antenna and RF unit.

When comparing forward and reverse signpost systems, there are cost trade-offs between:

- the lower cost proximity beacons versus the higher cost wayside readers; and
- the lower cost tags versus the higher cost signpost receiver and antenna units.

One final consideration is the method each type of signpost system uses to send location information from the field to the central site:

- The forward approach requires a radio communication system allowing each vehicle to send its location to central.

- The reverse approach requires each wayside reader to be connected to the central site system via land-lines or radio.

A comparison of these costs requires further investigation.

Forward and reverse signpost-based systems are normally used for fixed route applications only. Overall, system accuracy and cost are determined by the density of deployment.

3.2.2/ Dead-Reckoning-Based Systems

The basic operating principle behind a dead-reckoning-based system is that it can continually calculate and update a vehicle's relative position from a known starting point. This is done by constantly integrating the distance the vehicle travels and its heading. As long as the vehicle's starting point is known, the vehicle's location can theoretically be calculated from there.

Various sensors are used to determine the distance a vehicle travels and its heading. These include differential odometers, digital odometers, magnetic compasses, accelerometers, and gyroscopes.

A basic dead-reckoning-based system monitors a compass for direction, the odometer for distance, and the difference in wheel revolutions for a fine adjustment on heading. Wheel revolutions are monitored as follows:

- the turning radius of a vehicle is indirectly proportional to the ratio of the difference in the distances the inside and outside wheels travel;

- the number of degrees a vehicle turns is directly proportional to the ratio of the distance travelled while turning to the differential wheel travel.

By monitoring the vehicle's unpowered front wheels, an onboard computer calculates the distance and direction the vehicle travels. Unpowered wheels are instrumented to avoid the introduction of errors caused by slippage or wheel spin. By constantly monitoring the vehicle's movement (i.e., distance and direction), a current position estimate can be produced relative to the known starting point.

Other types of dead-reckoning-based systems:

- calculate heading using an inexpensive gyroscope and a standard vehicle odometer for measuring distance;

- calculate vehicle heading and distance using a digital differential odometer;

- use a compass-type device for heading and the odometer for distance.

A common negative feature of all dead-reckoning-based systems is that they have no knowledge of the real geographical world. A dead-reckoning-based system must be told its initial location and heading by external means. After startup, the system only measures perceived changes as the vehicle moves. The system's calculated location is only checked against reality when it is reinitialized. Therefore, the longer a dead-reckoning-based system runs between initializations, the further its location estimates drift from reality.

Due to the accumulated error in the input data produced from the system's non-ideal components, position settings need to be provided at frequent intervals. This can be accomplished with signposts on fixed route systems and with map-matching techniques to further enhance the system's accuracy. A map-matching program, running on the vehicle's or central site's computer system, is used to keep the vehicle on track.

However, problems can still occur. It is always possible for distance or heading data to be lost. This causes the position of the vehicle to be lost by the dead-reckoning-based system and requires manual intervention to correct. Under a worst case scenario, if the central computer goes down, every onboard system in the fleet would require the driver to reinitialize the system at a known location or starting point.

Some dead-reckoning-based systems now perform the position determination and tracking onboard the vehicle. In this arrangement, a loss of the central computer does not require onboard reinitialization.

Approximate Costs: Dead-Reckoning-Based System

Wheel Monitoring Equipment	$200
Data Monitoring Equipment	$120
Total Onboard Equipment per Bus	**$320**

The above costs are an example of the type of equipment a standard dead-reckoning-based system might consist of. Costs do **not** include onboard microprocessor unit or radio interface. Except for possible quantity discounts from suppliers, the per vehicle cost of onboard equipment is the same for a 50- as a 150-vehicle fleet.

A dead-reckoning-based system can be used for both fixed route and demand responsive systems.

3.2.3/ Land-Based Radio Location Systems

Land-based radio location systems typically operate in one of two ways. In the forward approach, the vehicle receives synchronized signals from three or more remote stationary transmitters. In the reverse approach, the vehicle sends a reference pulse or signal which is picked up by three or more remote stationary receivers.

The time differences of signal reception and the geographical location of the remote stationary transmitters or receivers provide the basis for calculating the position of the vehicle.

Unlike signpost-based systems, vehicles can be far away from the reference transmitters or receivers, in some cases several thousand kilometres. This means that only a few receiver or transmitter stations, strategically located, cover a very wide area. However, signals may have to travel large distances between a vehicle and a station and reception may be impaired by electromagnetic interference (EMI), radio frequency interference (RFI), terrain, weather, and high-density urban centres.

Land-based radio location system characteristics also differ from those of dead-reckoning-based systems because they provide absolute (i.e., longitude and latitude coordinates), not relative location. Dead-reckoning-based systems are blind to external geography and land-based radio systems are extremely aware of, and influenced by it.

3.2.3.1/ LORAN-C

LORAN-C (Long Range Aid to Navigation) is a hyperbolic land-based radio navigation system that uses low-frequency waves to provide signal coverage on land for up to 1500 kilometres. Stations are typically 1100 kilometres apart and coverage is independent of any line-of-sight.

In North America, the infrastructure of LORAN-C transmitter chains is provided free of charge by the national governments. While initially implemented for marine navigation in coastal waters and harbours, LORAN-C coverage is available throughout most of the United States and southern Canada.

LORAN-C signal coverage is provided using sets or chains of three to five LORAN stations. Each station transmits time-synchronized signals in the form of groups of pulses. In each chain, one station signal is designated as the *master.* The remaining two to four stations' signals are identified as the *secondaries.* The normal broadcast sequence in any given LORAN-C chain is as follows: the master station broadcasts first, followed by the secondary transmitters in a pre-defined sequence.

Although LORAN-C signals are complex, the LORAN system principle of operation is simple. Since radio waves travel at the speed of light (186 000 miles per second), a

LORAN receiver can calculate the distance a series of radio waves has travelled from their origin by the time they were delayed from a reference signal. In practical terms, a LORAN-C receiver is able to measure the *Time Difference* (TD) between the reception of a chain's master signal and each of the secondary signals that follow.

Location determination is accomplished by the reception of each transmission and its associated timing. With this information, the receiver can theoretically locate itself anywhere on the earth's surface. A LORAN-C receiver system, operating in a given coverage area, under normal conditions, can provide position accuracy of approximately 500 metres or better.

A variation on the basic LORAN-C system is *Differential LORAN-C.* With a differential system, a LORAN receiver is placed at a reference station where the exact position is known. Any natural disturbances or disruptions to the received LORAN signals will appear in the reference receiver's TD calculations and can be identified.

Naturally occurring location errors (e.g., due to atmospheric conditions or soil conductivity) can be *masked-out* of the location calculations for all remote receivers in proximity of the reference station. Typically, the reference station will provide reliable correction data for remote receivers within a radius of 30 to 50 kilometres from the reference station.

Error corrections can be handled in two ways:

- the correction can be made on the central computer as remote units transmit their TD information back to central site;
- a reference signal can be transmitted to the remote vehicle receivers and applied in their position calculations.

Differential LORAN-C systems can provide location accuracies in the order of 15 metres.

One major drawback to any type of LORAN-C system for land vehicle location is its susceptibility to RFI and EMI. This interference comes mainly from being in close proximity to overhead power lines and substations in urban and industrial areas. The interference may cause significant errors (±330 to 1000 metres or more) in TD position calculations. Other problems with loss of signal arise in downtown urban cores with very high structures.

3.2.3.2/ Omega

The Omega system is a low-frequency land-based radio navigation system operating in the frequency range of 10 to 13 kilohertz. The system provides almost complete worldwide coverage (90%) using eight stationary transmitting stations located about

8000 kilometres apart. The infrastructure of transmitters is provided free of charge by national governments.

Omega systems calculate location information by measuring the relative phase difference of the received signals. The accepted accuracy of Omega is about 3.7 to 7.4 kilometres. Actual accuracy depends on several factors, including geographic location, the stations used in calculating location, whether propagation corrections are employed, and time of day.

The main limitation of the system is that accuracies can vary according to changes in the height and behaviour of the ionosphere. This results in signal propagation errors and can vary from place to place, with the time of day, and the season.

Differential Omega systems, using fixed reference stations, can provide much improved location accuracy. Fixed monitor stations can identify local errors and calculate differential corrections. These corrections can be broadcast to system users in the local vicinity. A suitable receiver can then apply these corrections automatically to the phase-difference measurements from the basis signals.

An Omega-based location system will update a vehicle's location only once every 10 seconds. If location information is required more often, vehicles require a dead-reckoning-based system as well.

Tests performed in the centre of London, England by Andrew Stratton provide an encouraging note. The results published in *The Royal Institute of Navigation, Journal of Navigation* (Vol. 40, No. 3, 1987) show that the presence of buildings did not degrade Omega signals and 95% accuracy was maintained to within 300 metres.

3.2.3.3/ Reverse Approach Systems

Commercially available reverse approach land-based radio navigation systems use transmitters on the vehicles and a chain of receivers to apply triangulation techniques to determine vehicle position.

In a typical system, the vehicles are polled individually (similar to a paging system). When polled, the vehicle's onboard equipment transmits a beacon signal, which is detectable by the system's strategically placed receiver stations. Using the TD between reception of the vehicle's beacon at each of the different receiver stations, the location of the vehicle is calculated.

The vehicle location is determined at a central site and the individual vehicle location information is distributed to the various fleet operators over land-lines.

One major disadvantage of these types of location systems is that the infrastructure for a national system is not in place. Unlike the LORAN system, these systems cannot tap

into an existing network providing nationwide coverage. The polling and receiver system is expensive to set up and requires multiple receiving towers in any metropolitan area that wants the service. System implementation must start from ground zero and be rolled out city by city. This takes lots of time and money.

Unlike LORAN- and Omega-based systems, the trend to date has shown that reverse approach systems are being promoted and carried out by private commercial ventures. The infrastructure and major central processing costs are being borne by the private sector. In return, users are being charged a monthly service fee. This presents an opportunity for some transit properties in large urban areas where a system is installed to use these commercial facilities as part of their AVLC system. While the initial capital cost of a reverse approach system may be lower than those of a forward approach system, in the long run the on-going operating costs may well exceed any initial cost savings or benefits.

Quiktrak

In the metropolitan area of Sydney, Australia, an automatic vehicle location system called Quiktrak has been operating since 1987. The system has been designed to provide coverage over an area of some 2000 square kilometres with an accuracy of about 30 metres. The system also employs spread-spectrum techniques to provide accurate locations on moving vehicles in the severe multipath environments encountered in heavily built up areas. Vehicles carry an inexpensive radio transponder which can be activated at any time by radio control or by an action on the vehicle. Signals from the vehicles are received and processed at the receiving sites strategically located approximately 15 kilometres apart throughout the coverage area. The receivers measure the signal time-of-arrival relative to a system-wide timing-reference signal broadcast from the central location, and pass this information to the central processing site via land-lines. The central processing site calculates the positions of vehicles, then sends the co-ordinates to the users' central control over land-lines. User display technology may be a Quiktrak Track Display Station which superimposes vehicle symbols on a colour map.

International Teletrac

International Teletrac of Inglewood, California, has demonstrated a reverse approach system employing spread-spectrum digital transmission technology. Spread-spectrum communication techniques reduce multipath and other signal interference problems. The Teletrac system operates in the 908 megahertz frequency range and, because of the shorter wavelengths, should support a greater tracking precision than systems using LORAN-C.

The basic system operation is as follows:

- The fleet operator's central control has a graphical computer workstation running Teletrac's Vehicle Location System (VLS) application software. To determine a vehicle's location, a request to poll the vehicle is sent to Teletrac's Master Station.

- The Master Station verifies the validity of the user request. The paging transmitter(s) is then instructed to page the user's vehicle. The paging transmitter outputs a signal containing the digital address of the desired vehicle's onboard transceiver.

- In-vehicle transceiver is called a Vehicle Locator Unit (VLU). The VLU detects its address in the page and briefly outputs a response signal.

- Receiving antennas, located throughout the coverage area, detect the incoming signal from the VLU. The differences in the time of arrival of the VLU signal at each antenna site allows the computation of the exact location of the vehicle.

- The vehicle's location, along with any other information that may have been transmitted by the VLU in response to the page, is sent from the Master Station to the user. The vehicle's position is updated on the user workstation's graphical electronic map display.

The paging, receiver, and user sites are all connected to the Master Station via telephone land-lines. Teletrac says its system is accurate to within 30 metres.

International Teletrac aims to be strictly a carrier. The company has developed its own transmitters and has presently licensed the technology for manufacture by Samsung and Mitsubishi. Negotiations are also on-going with other manufacturers.

Teletrac will begin service in Southern California this year and is planning to install systems in several American cities. Detroit should have an operational system later this year. It is possible that Teletrac systems will be installed in some Canadian cities as well.

Estimated Costs

The onboard LORAN-C equipment consists of a LORAN-C receiver and antennas. The cost of these units is in the order of anywhere from $1500 to $2800 per vehicle.

Current Omega receivers are more costly than LORAN-C. However, volume production could bring the unit cost of Omega receivers down. The cost of installing and maintaining the LORAN-C and Omega transmitters is borne by the national governments.

The hardware prices of the two reverse-approach systems discussed will probably be less than $600, while monthly service fees will be in the $25 to $35 range for each vehicle, depending on the number of subscribers and the application.

Land-based radio location systems may be used for both fixed-route and demand-responsive systems.

3.2.4/ Satellite-Based Radio Location Systems

Satellite-based radio navigation systems may also be operated as forward- or reverse-approach systems. The functionality is roughly comparable to that of land-based systems, except that satellites are used to transmit (forward) or receive (reverse) location signals.

In the forward approach, the system operates by precise timing of signals transmitted from a ground station, through two to twelve satellites, to a vehicle's onboard receiver. The receiver compares the difference in the time of arrival of signals routed by each satellite and calculates the distance of the receiver from each satellite. This leads to a position fix in two or three dimensions through triangulation techniques.

In the reverse approach, the vehicle is polled and responds by transmitting a beacon which is received by a series of satellites. The positioning information is then processed and the vehicle's location determined at a ground-based central control site. Location information can then be sent over land-lines to the vehicle's fleet monitoring centre.

3.2.4.1/ Global Positioning System

The Global Positioning System (GPS), also known as Navstar, or Navstar/GPS, is a U.S. military satellite-based radio navigation system. The system presently uses 16 satellites to provide two-dimensional positioning anywhere on earth, 24 hours a day. Three-dimensional coverage is also available about 12 to 16 hours a day. The full system will eventually be comprised of 24 satellites; 21 satellites will be used to provide three-dimensional coverage, worldwide, 24 hours a day, and three satellites are to be used as backups.

The military capabilities of the GPS system, using the Precision Code (P Code) signals, is designed to support ten-metre accuracy or better (practically, it has been found to be three metres or better), anywhere on earth. The Standard Positioning Service (SPS), designed to operate with an inferior signal quality, offers a lesser degree of accuracy for general commercial and civilian use. According to Scott Lewis, Vice President of Acrostar, an Ottawa-based engineering company specializing in GPS technology, the accuracy of the Course Acquisition Code (CA Code) signals, which is the SPS portion of the GPS system, is suggested to be between 30 and 100 metres, depending on the extent to which the signal quality is intentionally degraded by the U.S. military.

A vehicle equipped with a GPS satellite location receiver will be provided with its position (i.e., longitude and latitude coordinates) precisely correlated with time about once every second. GPS receivers are sophisticated, with complex timing and computation functions. Right now, costs are high, but are expected to fall dramatically in the near future as more and more units are mass produced.

In the United States, the Department of Transportation (DOT), Transportation Systems Centre, ran extensive tests of GPS/SPS receivers. The receivers were mounted on land-based vehicles in rural and urban settings. (Comparison tests were also run on LORAN-C receivers on land-based vehicles.)

Highlights of the overall study were as follows:

- GPS receivers could not maintain accurate navigation position on streets flanked by buildings of 10 or more stories;

- LORAN-C receivers lose signal lock when within 120 metres of a power substations, but recover once clear of the area;

- GPS receivers do not experience problems from the above-described type of interference but can be obstructed by foliage (i.e., loss of the line-of-sight with locating satellites).

Unfortunately, GPS is strongly affected by the specific urban environment. Specific problems include: multipath signal propagation, signal attenuation by trees, blockage of satellite visibility by buildings, and complete satellite shielding by tunnels and subways. These factors combine to reduce the availability and accuracy of the navigational information.

Differential GPS (DGPS) represents a potentially cost-effective method of significantly improving the accuracy of a GPS-based system. Like Differential LORAN-C, a DGPS system would operate a reference receiver from a known location. The true values of this receiver's navigation fixes are compared to the measured values and the differences become the differential corrections. These corrections can then be sent to GPS receiver sets in the fleet's service area, in real-time, so that corrections can be applied to the navigation data on the remote mobile sets. DGPS is predicted to provide accuracies in the area of three to fifteen metres.

Estimated Costs

The cost of a LORAN-C receiver, including antenna and pre-amp, varies depending on whether the receiver is a single board for insertion into an in-vehicle data control unit or a self-contained, stand-alone receiver. Prices range from about $1000 for a board to $3000 for a full unit. GPS receivers are now about $850 to $1500 per unit **less** expensive than LORAN-C receivers but are expected to eventually cost about the same.

Satellite-based location systems can be operated with vehicles in a fixed-route or demand-responsive role.

3.3/ Map-Matching

Map-matching is a location-refinement technique performed by software. The map-matching programs analyze a continuous flow of vehicle location information. The resulting positioning information is adjusted according to a digital (digitized) map stored in a database. Map-matching software is available to run on a vehicle's onboard data system as well as on the larger central site computer systems.

In the first case, the positioning information is corrected to match the digital map of the vehicle's route and surrounding area, stored in the vehicle's data system. This adjusted or matched location information is then sent to the central site.

In the latter case, raw location data from the location system is sent back to the central site where the host computer then applies the map-matching techniques to the data, thus correcting any obvious positioning errors.

The digital road map uses junctions or intersections as nodes; the routes between nodes are regarded as links. While conventional map-matching techniques can correct vehicle position along the route for encounters such as corners (i.e., at intersections), problems can occur.

For example, driving methods at corners differ from driver to driver. Also, since map data represents a road as a group of vectors, the shape of a corner on a map data often differs from the actual corner. These examples show why sophisticated and complex processes and algorithms are required for extracting characteristics and matching judgements.

One map-matching technique corrects position tracking along straight lines. If a vehicle travels a certain distance without varying beyond a specified angle, the road is considered straight. As described in the next section, map-matching techniques can be used improve the reliability and accuracy of many different location systems.

One final note of caution. Digitized map databases are only as accurate as the original maps from which they were created. For example, TTC in Toronto has found that the database it created from conventional Statistics Canada maps is as high as 20% inaccurate in some instances. TTC is now looking at creating its own in-house maps using satellite-based images.

3.4/ Hybrid Systems

There are four fundamental techniques used in solving the problem of location for a fleet of vehicles:

- proximity signpost
- dead reckoning
- radio-location: ground-based
- radio-location: satellite-based.

It is generally accepted that any one of these techniques cannot, on its own, provide an adequate solution. However, by using a combination of two or more of these techniques, or by augmenting any one of them with computer aided map-matching, one can achieve reasonable accuracies on a continuing basis.

In simple terms, the difficulties that face location systems can be summarized as follows:

- Proximity signpost-based systems may present problems associated with the large number of signposts needed over a given service area. The density and location of signposts will determine the overall location system accuracy. In practice, it has been found that city centres require higher densities, while fewer signposts are needed towards the periphery. A second problem with signpost-based systems is the lack of off-route vehicle tracking capability.

- Dead reckoning relies heavily on accurate turn and heading data, which may be easily corrupted by uneven road surfaces, steep hills, or magnetic interference. A heading sensor is the most critical component of the dead-reckoning system. Heading errors can be reduced by judiciously siting the compass within the vehicle, using small compensating magnets, and performing final calibration after installation. However, very little can be done about heading errors due to external magnetic interference.

- Ground-based radio location systems suffer from blocking and distortion of the radio signals, potentially yielding erroneous position and, at worst case, no position at all. The time to recapture signal lock may also impact the location system performance.

- Satellites give excellent position but only if enough satellites are in line-of-sight with the receiver. Time to reacquire signal lock after losing line-of-sight with a given satellite can also affect positioning system performance.

It is apparent that no one positioning technology or location system guarantees absolute accuracy in all location situations. By considering the failings of each positioning technique, it is possible to compensate one with another to improve performance, accuracy, and reliability. The goal is to make systems complementary rather than mutually exclusive. Table 1 illustrates the possible combinations of various location systems discussed.

Table 1/ Hybrid Location Systems

Location System	LORAN	OMEGA	GPS	Map-Matching	Dead Reckoning	Signpost
LORAN			•	•	•	•
OMEGA					•	•
GPS	•			•	•	•
Map-Matching	•	•	•		•	•
Dead Reckoning	•	•	•	•		•
Signpost	•	•	•	•	•	

Specifically:

- dead-reckoning-based systems provide good short-term stability but exhibit excessive medium- and long-term drift over distance travelled;
- radio-based systems are characterised by short-term instability (in built-up urban areas where the best accuracy is required), but do, however, exhibit excellent long-term stability and repeatability.

Generally:

- a dead-reckoning-based system may be combined with virtually any type of location system;
- map-matching techniques may be used in conjunction with most location systems to enhance the location system accuracy;
- by combining a dead-reckoning-based and radio-based location system into a hybrid system, the drift of the dead-reckoning-based system may be estimated and compensated for over time and the dead-reckoning-based system can be used to drop impossible position numbers generated when the radio-based system loses signal contact;

- by combining a dead-reckoning-based and signpost-based system, the drift of the dead-reckoning-based system can be corrected periodically at common points along various routes (i.e., at garages, terminals, and major transfer points).

- by combining GPS with a dead-reckoning-based system, the GPS system can be used as a "portable signpost" to provide accurate position fixes at predetermined timepoints while the dead-reckoning-based system provides the location information between the timepoints or position fixes.

3.5/ Central Site

3.5.1/ Computer System Hardware

Central site computer hardware platforms can be broken down into four major classes:

- mainframe computers
- mini and super-minicomputers
- workstations
- desktop computers (PC).

The choice of which type of hardware platform to use for a transit property's AVLC system depends on several factors. Both the size of the property and the extent to which the AVLC system will be integrated with other transit computer systems must be considered.

Transit properties must also consider whether existing systems will be kept and upgraded or an entirely new system designed, built, and installed from scratch. Whether the AVLC system will be running as a stand-alone system or as part of the overall day-to-day operation will inevitably affect the selection process.

Further complicating the choice of hardware platform is the advance in desktop and workstation technology. While super-minicomputers have been approaching the processing power of older-model large mainframe computers for some time, workstations have recently been made available in the marketplace that challenge the processing power of the minicomputer.

The line of distinction between low-end workstations and powerful 32-bit microprocessor-based desktop computers is also blurring. Another recent development is the ability to share both hardware and software resources by networking workstations, desktop computers, and larger computer systems (i.e., mini and mainframe).

The trend in the past has been for large and medium transit properties to build their computer systems around the Digital Equipment Corporation (DEC) VAX and MICROVAX line of processors and workstations. This is because there was a large amount of transit software written for the VAX, in particular, scheduling software.

The decision of which type of computer hardware platform to install for the implementation of an AVLC system will also depend on the requirements of the transit property's management, administration, operations, and end users. Ultimately, the choice of the AVLC system central site computer hardware should be based on, but not limited to, the following considerations:

- the size of the transit property, and hence its computer requirements and resources;
- the type of location system chosen and whether vehicle location and positioning will be determined in-house, in the vehicle's control unit or by a third-party off-site system;
- the type of computer hardware and systems existing within the property's computer and transit control facilities;
- the number of users (management, controllers, staff) requiring on-line and off-line access to the AVLC and general transit computer system;
- the extent to which the AVLC computer system will be integrated into the radio communications system;
- the extent to which the AVLC computer system will be integrated into the existing property's day-to-day computer operations;
- the extent to which the AVLC computer system will be integrated into any future or planned expansion of the property's day-to-day computer operations;
- the choice of the property's other transit software and software systems, both existing and planned;
- the extent to which all transit software, including AVLC system software, will be custom developed in-house, bought as a package, or any combination of the two;
- the type of display station technology required (i.e., windowing, colour, graphics, electronic digital mapping);
- the type of database to be used (central or distributed, relational or hierarchical), and the shared access to the database by all existing and future transit property computer systems.

One advantage of implementing networks is that distributed and shared databases can be implemented. All the various types of hardware platforms available could theoretically *hang off* this network, with the actual type of hardware determined by the type of, and requirements of, the individual departmental end users.

The following is an example of one possible configuration for an integrated transit information system:

- Controllers use a mix of workstations and high-end desktop computers in a multi-window, multi-session environment to monitor and control the transit property's fleet.
- Planning and management personnel use less expensive desktop computers and terminals for day-to-day property administration.
- Public information users use low-cost terminal display stations to provide real-time schedule and trip planning information to the public.
- All departmental systems are on local area or wide area networks and have the capability to communicate with and share information from various distributed databases.

Smaller properties might only carry out a portion of the above, suitable to their individual needs, size, and requirements.

In the case of a transit property with a large fleet of vehicles, an AVLC system may actually require two types of computers:

- a front-end computer or computer system to control the central site's fixed communications facilities, send messages to vehicles, receive and check vehicle responses, control sequential processing of data, and communicate with the host computer;
- a host computer or computer system to control the front-end computer, determine the location of the fleet's vehicles, present location information in graphical or tabular form, control transmission of commands by the control centre operator, store desired information in a database, and analyze stored and real-time data in various ways.

3.5.2/ Communications Data Control System

The central site AVLC communications data control system is a dedicated system controlling communications between the central computer system and the remote fleet. It is the interface between the central site computer and communications subsystem.

The functionality of the communications data control system includes:

- conversion of incoming analog radio signals to digital data
- conversion of outgoing digital data to analog radio signals
- error detection and correction
- protocol conversion between systems.

The actual size of the communications data control system may vary, depending on the size of the transit property, the number of vehicles to be polled, the amount of data to be collected with each poll, and the type of AVLC system implemented.

Small transit properties may require only a simple programmable hardware device to perform the necessary functions. Larger properties may require a fully functional frontend (computer) processor to perform data communications handling, vehicle polling, and polling table maintenance for the property's fleet.

The need to perform protocol handling in the communications data control system will depend on the type of system in use. Most computer and communication systems available on the market use a protocol to pass data between them. Some protocols are open and are based on internationally accepted standards. Others are closed and use standards that are proprietary and unpublished. In some cases, customization is necessary to create data compatibility.

The communications data control system may also be responsible for routing incoming vehicle data and driver communication requests to the correct computer control system (i.e., multiple control rooms), individual controller or dispatcher consoles, or a special emergency response centre for high priority and emergency messages. Some communications data control systems can decode enough of the incoming messages to determine a routing address. The partially decoded message is then sent to the right destination.

Some AVLC systems also use the communications data control system to assign channels to allow controllers and dispatchers to communicate with drivers over the two-way radio system. The controller, when starting a request or responding to a driver request, is assigned a communications channel, from an available pool of channels. The communications data control system will monitor and control access to the channels.

3.5.3/ Communications

Data and voice communications between the transit property's fleet and the central control is typically handled using digital communications. The data and voice communications may be separate systems, but in most cases they are combined. Where possible, existing voice radio systems are upgraded to provide data communications.

Regardless of the functionality of the communications system (i.e., data, voice, or both), some infrastructure is required in the form of transmission and receiving towers and antennas. This cost is borne by the transit property and is directly proportional to the size of the property, the size of the service area, and the environment of the service area (e.g., dense urban, hilly, flat). However, if an existing radio system can be altered to suit the new AVLC requirements of the property, some cost savings can be realized.

There now exists a backbone cellular network available in most urban centres throughout Ontario. While the cost of using this network as the primary means of communications would be extremely high, the network does provide an excellent means of creating a backup and emergency voice communications system with no additional cost to the existing or future communications infrastructure. In addition, small, dedicated cellular equipment has recently dropped significantly in price, with further reductions expected as the technology continues to mature.

The choice of location technology may lessen the need to have data transmission capability from the vehicle. In such circumstances, there is no need for a data system interface as well. (This may occur when implementing a reverse approach vehicle location system.)

3.6/ Vehicle Equipment

The type and the necessity of onboard and in-vehicle equipment depends on the following three factors:

- the type of location technology
- the type of communication equipment
- the type of driver interface (i.e., display, keypad, handset).

Table 2 summarizes some of the onboard equipment required based on the type of location technology employed by the AVLC system. Assuming all transit vehicles presently have two-way radios, the onboard equipment may consist of:

- a mobile radio unit and antenna for voice (and possibly data) communications;
- a data control or vehicle logic unit, possibly combined with a driver control head consisting of an LCD display and keypad;
- different types of location sensing, receiving, and transmission equipment, dependent on the type of location system used;
- a handset for driver voice radio communications.

Additional onboard equipment may also include a microphone or speaker for hands-free driver voice communications and a multiple speaker Public Address (PA) system for driver and possibly central control broadcasting.

Within the onboard data control system or vehicle logic unit, a low-cost microprocessor can be integrated with the communications and location technology. The fully integrated system can perform any of the required complex mathematical coordination, grid conversion calculations, and control of the data/voice radio, driver display, and status light panel.

Table 2/ Comparison of AVLC Location Equipment

Onboard Location Equipment Description	Radio Location		Signpost Odometer		Dead Reckoning
	FW	RV	FW	RV	
Mobile Data/Voice Radio Unit (with antenna)	D/V	V	D/V	V	D/V
Driver Data Display Unit	O	O	O	O	O
Mobile Data Modem/Electronics	R	O	R	O	R
Electronic Compass, Gyroscope, Sensors	–	–	–	–	R
Electronic Beacon/Poll Receiver (with antenna)	R	R	R	–	–
Passive/Active Electronic Tag	–	–	–	R	–
Odometer Interface Unit	O	–	O	–	R
Wayside Equipment (signposts, readers)	–	–	R	R	–
Radio Navigation Receiver/Transducer (with antenna)	R	R	–	–	–

KEY: FW = Forward
RV = Reverse
D = Data Only
V = Voice only
R = Required
O = Optional
D/V = Data, Voice, or Both
– = Not Applicable

In addition to the AVLC-related equipment and mobile radio, the data control unit can be interfaced to a number of other onboard systems. These additional systems may include:

- passenger counter
- electronic fare collection equipment
- power/heating/air conditioning monitor
- engine management system.

An example of what a fully configured vehicle *might* look like is shown in Figure 1.

3.6.1/ Driver Displays

In some AVLC implementations, transit properties may choose to outfit each vehicle with a driver display or control head. The driver display may be stand-alone or fully integrated into an onboard data control system. Typical technology for the display screen is an LCD, although a fully functional remote terminal with CRT display and keyboard is available for supervisor and maintenance crew vehicles. The number of lines of text displayed on the screen may vary from a simple eight alpha-numeric character message to several 40- or 80-character lines.

The kind of information displayed to the driver may include, but is not limited to:

- system clock or time of day
- system status messages (i.e., logon, logoff, standby)
- vehicle status messages (i.e., engine alarm)
- messages from central control
- schedule adherence messages (± number of minutes).

Most AVLC systems may provide, in addition to or instead of an LCD screen, a status panel of message lights. The lights are lit when appropriate and otherwise blacked out. The type of information indicated by the lights may include:

- power on and off indicators
- transmit message and receive indicators
- call pending indicator
- message and request acknowledged indicators
- engine and emergency alarm indicators.

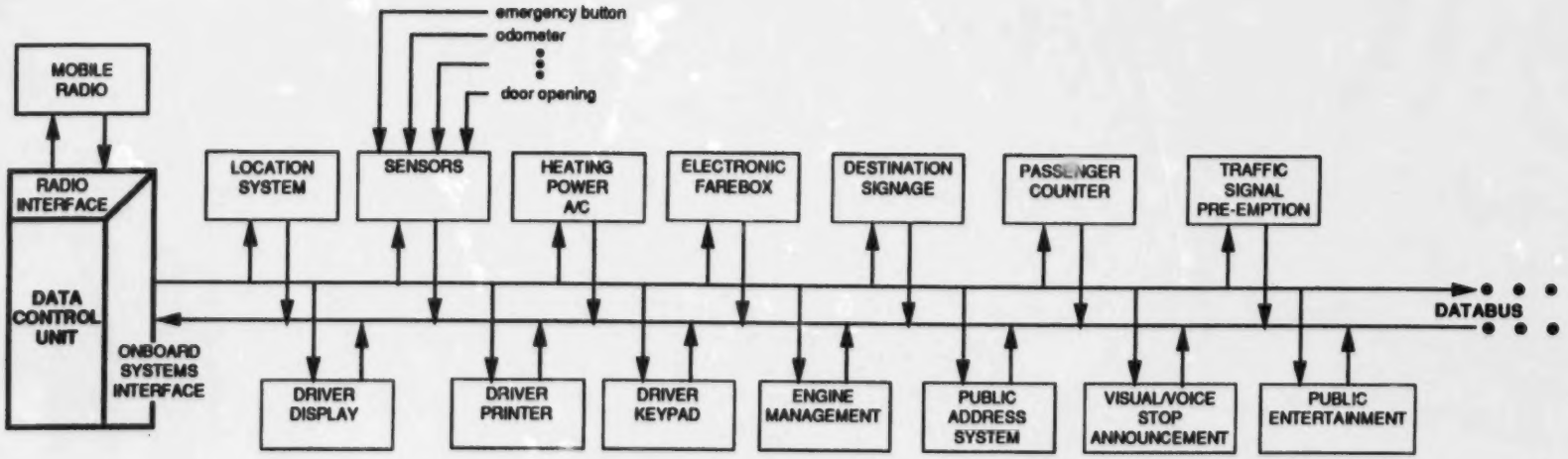

Figure 1/ Example of Onboard/Vehicle Architecture

3.6.2/ Driver Communications

When required, a two-way mobile radio unit is fitted to each vehicle. If the type of location system employed does not require the radio for data transmission, a conventional two-way mobile radio unit will suffice.

Some radios can be fitted with a device and programmed to allow the central system to display, on the controller's terminal screen, the vehicle number and driver ID of each incoming call.

If the type of location system employed requires the vehicle data control system to send information to the central site, the radio unit will be integrated with the data control system to provide the required communications facilities. The resulting unit provides the data control system with the capability to transfer information, over the radio, to and from the vehicle and central control. During regular voice communications, the data control system behaves as a normal mobile two-way voice radio system.

3.6.3/ Driver Functions

Most AVLC systems with in-vehicle data control systems require manual entry of the driver ID and route/run information at the start of the shift. This information is then compared to the schedule for validation. The vehicle number may also be required, depending on whether or not the number has been hardcoded into the system. Personal and confidential IDs, such as the driver's payroll number, which is normally not told to other drivers, may be used. This helps to verify that daily assignments are being carried out by the appropriate driver.

Another type of system eliminates the need for the driver to enter any initial startup information through the use of electronic tags. With this approach, a tag is permanently fixed to the vehicle to supply the vehicle number and a portable one is attached to the front of the vehicle by the driver to supply driver ID and route/run information. When the vehicle leaves or enters the garage facilities the information is then automatically captured electronically by a wayside reader. OC Transpo is investigating the use of this type of system to automaticlaly provide block/assignment information to their AVLC system.

For vehicles fitted with data control systems and display units or driver control heads, there are several functions available to the driver. Normally available are:

- a Request To Talk (RTT) button for requesting normal voice communications
- a Priority Request To Talk (PRTT) button for urgent communications
- an Emergency Alarm (EM) provided for emergency or life-threatening situations.

The emergency alarm feature is effectively a silent alarm, providing no in-vehicle signs of activation.

AVLC systems that provide pre-encoded messages to the driver from the central control may reduce the amount of normal voice-radio traffic required. They also provide the central control with the ability to notify drivers to wait for a transfer, slow down, skip a stop, or short turn without using the voice radio. On some systems, a driver can report such incidents as heavy traffic and empty, full, or standing-room-only conditions.

3.7/ Radio System

The quality of a transit property's existing two-way voice radio system will dictate the upper performance capabilities of any future supplementary data system implemented. If a property's radio system is being replaced at the same time as the AVLC system is being implemented, the radio system should be designed to meet current and future performance and load expectations.

However, many transit properties are presently in the process of only replacing or upgrading old and obsolete radio equipment. Those properties anticipating the possible future implementation of AVLC must carefully consider the data communication system performance expectations during the selection of their mobile radio system platform.

3.7.1/ Radio System Platform

Statistics have show that up to 90% of all voice/data transmissions to a transit vehicle can be accomplished using coded and short displayable text messages. Similarly, the majority of vehicle to central voice/data transmissions can be delivered in the form of push button status messages.

In summary, most AVLC system related radio traffic is in the form of short data bursts. Therefore, a transit AVLC radio system should be designed primarily for the efficient transmission of short, frequent data messages. The use of voice should eventually become a backup, emergency, or secondary application.

While AVLC data communications can occur using a multiplexed (i.e., voice and data on the same channel) approach, one or more dedicated data channels, depending on the volume of data and size of the fleet, is usually preferred and recommended.

3.7.2/ Trunk Radio Systems

An increasing number of municipalities, cities, and regions are investigating the feasibility of implementing shared trunked radio systems. In such situations, shared users might include police, fire, ambulance, public works, and transit.

Trunked radio systems use communications and microcomputer technology to pool any number of radio channels for a large single user or a multi-user group. Systems

use a dedicated control channel which is monitored be all mobile radios. The control channel manages the radio traffic by directing channel access request to an available operations channel in the pool.

A trunked system is between two and seven times more spectrum efficient than conventional mobile radio systems, because it makes optimal use of the available radio channels.

To date, most trunked systems are designed predominately for voice communications and have limited short burst data capabilities. Delays of up to 500 milliseconds can be experienced while the control channel processes a request and then instructs the appropriate mobiles in a given talk group to switch to an assigned operations channel. A delay in this range is quite tolerable for voice communications but may be too slow for certain data communication modes.

A typical trunked system should be able to effectively download a large volume or block of data (i.e., a screens of information for a mobile data terminal installed in a police car). However, short burst data transmissions, as would be required for an AVLC system to poll and receive data from a fleet of transit vehicles, may present a problem.

For example, a typical AVLC system using dedicated conventional data communications might be capable of polling five to ten vehicles per second (i.e., 300 to 600 in one minute). On the other hand, an AVLC system utilizing a voice trunking system might be capable of polling only one or two vehicles per second (i.e., 60 to 120 per minute).

More significant to the AVLC application than potential polling capacity problems, however, is the use of channel priority levels by shared trunking systems. Shared trunking systems may be implemented so that emergency voice/data radio traffic (i.e., police, fire, and ambulance) is given priority over all other users. This could effectively inhibit a transit property's use of the system during peak public safety user use or during public emergencies.

Transit AVLC radio systems must be designed primarily for data communications with added voice capabilities. Trunked radio systems are designed primarily for voice traffic with added data capabilities. In light of this problem, newer trunked radio systems are now being designed that will be optimised for data rather than voice traffic.

3.8/ Software Systems

The software system and application programs installed by a transit property to support and operate its AVLC system may be created or obtained in three ways:

- software is custom designed, developed, and tested in-house by the property's Management Information Systems (MIS) department, possibly assisted by outside contract consultants, designers, and programmers;

- software is purchased as a complete off-the-shelf package or a series of software packages from one or more vendors;

- a combination of the above, where some software is purchased as packaged and the remaining software is custom developed.

If a total custom approach is chosen, then all the system user requirements can be incorporated into the designed solution. However, the transit property will have to bear the full research, design, development, and testing costs of producing the software. In addition, post-implementation software maintenance and support must also be considered.

If a total package approach is chosen, the overall costs may be much less, but the packaged software chosen may fail to meet all the transit property's requirements. Post-implementation support for software maintenance and upgrades may also be available from the suppliers at additional cost to the property.

The hybrid development approach uses as much packaged software as possible along with custom developed software to reduce the project scope and cost. This may be the best alternative for medium-sized properties. For the smaller properties, some packaged software suppliers will perform the customization required to suit the property's needs, eliminating the need to hire in-house or contract programmers.

There is a fourth possibility. This is to acquire an existing software system that has been developed for, and is in use at, another transit property. This is similar to the packaged approach, with the additional advantage of allowing the property considering the software to assess it under real-life conditions. However, the costs to incorporate any required changes or additional customization of the existing software, so that it could be used at another property, could potentially outweigh the advantages.

While the above alternatives seem realistic, the situation to date has been somewhat different. Most North American AVLC systems have been developed by systems integrators based on a quasi-operating standard combined with the contracting property's specifications. Since no one company can provide a complete turnkey system, sub-contractors have been used to supply or develop all or only a portion of the system and application AVLC software. Only a very small number of the larger properties have developed or are actually developing their AVLC software inhouse.

Presently, there is almost no complete off-the-shelf AVLC software package. In rare cases in the past, software was purchased as a complete off-the-shelf package only

when there was no need to design interfaces with communications, scheduling, or other transit computer systems.

3.8.1/ Modularity

It would be unrealistic to expect that any initial AVLC system implementation could immediately encompass all the goals and requirements of a transit property. It is also doubtful that the same system could be fully integrated with other existing transit computer systems without some additional design and development. Despite the fact that a fully integrated AVLC system may not occur for some time after initial implementation, the property should insure that this option is available should it choose to pursue it.

It is now widely known throughout the software industry that it is extremely important that a modular approach be used when implementing application and system software. The modular approach to application and system software development and integration implies that all software is developed in modules.

Each module is typically designed with a well defined set of inputs, outputs, and a distinct functionality. Providing each module is designed as a self-contained unit with a common interface, modules may be added or removed from the application or system with much less interdependence or complexity.

The main advantages of the modular approach are:

- the ability to *grow* or *shrink* a system and its applications as new requirements are identified or existing requirements are changed or eliminated;
- the ability to maintain, upgrade, and redesign pieces of an application or the system without altering unaffected modules or changing the general nature of the system;
- the ability to add, change, or remove entire system or application software subsystems;
- the ability to bring down or restart individual system modules or subsystems without affecting the users not requiring those modules or the subsystems.

This style or technique of application software development and system implementation lends itself to the approach of using a mix of both packaged and custom software in a single integrated system.

If the transit property's operation and required software system can be broken down into modules of functionality, then some functional requirements may be filled by package software, while others may have to be custom. The major challenge, therefore, will become integrating the application and system software modules as opposed to developing an all-encompassing solution that will inevitably become unmanageable down the road as additional functions are added, changed, or removed.

In addition to the system and application software, real-time software should be modular in design to allow for easier maintenance. Low-level, high-speed, time critical functions such as communications drivers and data protocol conversion routines should be written in a software language as close to the machine (hardware) level as possible.

Conversely, programs developed for higher-level functions should be written in well known and established high-level languages such as the C Programming Language.

3.8.2/ Database

Organizationally, central site AVLC databases tend to be logically divided into two entities. The first contains static data required to *support* a property's internal and fleet operations. The second contains data *produced* or generated by the system.

At present, there are no AVLC standards for the various sets of required data elements and their associated databases. However, an application data interface standard (the TARC interface), which has been under development for some time, is almost complete. The standard will define interface data files in ASCII between such applications as automated scheduler and any other system, AVLC and any other system, and vehicle maintenance, inventory, and purchasing and any other system.

Types of AVLC system data elements range from driver ID, schedules, and digital maps (static) to ongoing headway and schedule exceptions (dynamic and real-time) to hourly, shift, and daily exception reports (historical). Some of these databases or portions of the them are tied to one specific application or system function. Some are routinely accessed by many different application types.

The databases provide controllers and dispatchers with a wide variety of on-line information at their finger tips to assist in the real-time managing of the property's fleet. This on-line access eliminates the need for bulky printed schedules, headways, and paddles. Databases also are used behind the scenes by the system. The system determines where a given vehicle is, uses the databases to determine where the vehicle *should* be, and then stores selected data on both for later access and use. More advanced AVLC systems will use the data to provide travel time differences as a deviation from the current schedule.

It should be noted that AVLC systems are capable of producing massive amounts of historical data which must be collected, stored, and eventually archived. Determining what data is required for which on-line and off-line uses is a major challenge to those properties attempting to specify their AVLC system user requirements. Properties must ensure that their databases contain the information they require both at the time of AVLC system implementation and for future systems expansion and development.

The nature of the central site computer hardware platform and its configuration may play a part in determining whether an AVLC database will be created and stored centrally or distributed. Regardless of the overall size of the central site computer system, the contents of the databases may be centrally located on a single computer or distributed over many departmental computers connected in a network configuration.

Most modern AVLC systems are being designed to operate around a relational database management system to collect, access, and manage the data in a number of related files. AVLC databases should be compartmentalized and the stored data made available to other transit departments. This is what is meant by a shared database.

Transit property departments, other than transit operations and control, may require access, from time to time, to certain portions of the stored data produced by the AVLC system. For example:

- the planning department may wish to fine-tune schedules by periodically uploading actual real-time travel-time saved in the database and running it through a schedule analysis package;

- the payroll or finance department may wish to use portions of the real-time system to track driver hours and overtime;

- an Executive Information System (EIS) may access various databases in order to summarize and present information to the transit managers on such topics as schedule adherence on a route, district, or throughout the property, or percentage of fleet use during peak and off-peak hours;

- generic report generators, normally included with advanced systems, will access various databases in order to produce common or special reports in any format.

All these functions, and many more, can be integrated into the AVLC system's shared database. Systems do not have to be stand-alone, but can become part of the total transit property computer systems operation.

One final note concerning transit properties in the United States receiving partial funding from the Urban Mass Transportation Administration (UMTA). UMTA requires properties to use Section 15 reporting on information such as running times and schedule adherence. Since U.S. transit properties normally keep distances between timepoints in feet, this has led to signpost/odometer-base system popularity for AVLC and other schedule adherence applications.

For those systems which will provide information at timepoints using radio location technology (i.e., in an absolute longitude and latitude as opposed to relative feet from last timepoint), special software must be used in a more complex process to convert

the long/lat coordinates into a meaningful representation before schedule adherence calculations are performed. A transit property is then required to keep these specialized files updated to account for every route change.

U.S. transit property AVLC system specifications tend to require that the AVLC database fully support UMTA's Section 15 reporting. Schedule adherence, driver on-time performance, and revenue per stop are three important databases that must be available. In general, transit properties can use this data for possible schedule and route change decisions to allow their fleets to operate more efficiently.

3.8.3/ Functionality

AVLC system software may be fully integrated with transit operations involving planning, scheduling, dispatching, operations control, maintenance, marketing, and executive and management decision support. AVLC systems can be used to enhance the speed, accuracy, and comprehensiveness of the transit data collection and information dissemination process.

Some transit properties may wish to have AVLC software that meets the requirements of both a fixed-route and a demand-responsive transit fleet system. If this is the case, the software must be capable of tracking transit vehicles on fixed routes as well as vehicles that may be randomly distributed throughout the service area. Properties wishing to track the location of the supervisor and maintenance vehicle may use the same approach.

While the specific functionality of AVLC application software may differ from property to property, some basic features are common and may include:

- a shared relational database containing fixed and updatable data on the transit property, its operations, and the service area;
- support for radio communications (data, voice, or both);
- the ability to report planned and actual schedule conditions on- and off-line;
- headway control and the ability to supervise turnaround times;
- the registration and recording of all significant events including vehicle, driver, and route/run combinations, driver initiated events and alarms, and schedule deviation;
- an interface to an automated public information system;
- the option of real-time schedule changes to co-ordinate and control transfer;
- the facilities to evaluate statistical data collected to analyze transit operations;
- the handling of trip request registration and processing for demand routes;
- the software tools to aid in the design of routes for both fixed and demand services.

Most important, the AVLC software must allow for a flexible means of vehicle deployment. Vehicles may be deployed from the garage or from other routes to meet the demands of the riders, at any time or in any zone. This feature is inherent in the AVLC system's ability to continuously monitor vehicles, their occupancy and line loading, and

present the necessary data to the central control personnel. This in turn allows the controller or dispatcher to respond to varying ridership demands, traffic conditions, emergencies, and breakdowns. A second, and equally important aspect, is that the coverage of all transit vehicles, both for location tracking and voice radio communications, provides for the added safety and security of both the vehicle's driver and the riding public.

Most AVLC systems are designed for the central site personnel around operational constraints. Calling vehicles, replacing vehicles on road calls, replacing drivers, and calling drivers are only some of the commands available. Because large amounts of data is constantly pouring in through the AVLC system, many transit properties operate on an exception basis. This means that whenever the system detects a predetermined event or scheduling exception, it calls a controller's or dispatcher's attention to the event. The system reports only exceptions to the regular or adjusted service. Such exceptions could be:

- the prediction of a late arrival at a timepoint exceeding a preset limit at a predetermined time before arrival at that timepoint (e.g., a sliding 20-minute window);
- a stopover at a wrong recovery point;
- an inadmissible route/run combination or incorrect driver ID.

The exception, once reported, is usually handled by a controller (fixed route) or a radio dispatcher (demand responsive). The controller or dispatcher normally has a terminal screen displaying the queued driver voice communication requests. These requests are listed by priority, time of arrival, or both. The next call in the queue, or any call in the queue, may be selected. Any vehicle may be contacted by radio whether listed in a queue or not.

To monitor schedule adherence effectively, small- and medium-sized transit properties require as a minimum:

- a textual table listing, or a display on an electronic map, of each bus in service on its route with location and schedule adherence;

- a textual table listing of specific groups of buses or a zoom-in mapping capability so that an area of the municipality can be expanded to show the location and schedule adherence of every vehicle in that area;

- a textual table listing or a section of the map display screen showing the buses that will have problems meeting their preset schedule adherence limits or executing important transfer meets.

3.8.4/ Integrated Systems

As previously stated, a shared database is required for a transit property to fully integrate its transit computer operations. The integration of applications would be expected to take place in stages, possibly over many years.

The modular approach should be followed during system design and development to reduce the high capital costs of implementing an entire property-wide system as a single project goal.

An integrated AVLC system will need to provide access to different portions of the database for various functions such as line planning, scheduling duty rosters, operational control, operations supervision, and to provide riders with information. An example of a fully integrated property is shown in Figure 2. Note that the common "thread" between the various organizations within the property is the underlying relational database.

The planning department may desire off-line software functionality to analyze and evaluate fleet performance with a goal of improving service and developing and updating route and headway plans.

Scheduling (which may be part of planning) may require off-line functions to monitor past schedule exceptions, determine the deficiencies in the existing schedules, and develop new vehicle and driver schedules to meet these requirements.

Operations control and dispatching require on-line functions to check the status of fleet resources and assign available vehicles and drivers to meet the daily requirements of the schedule and current scheduling exceptions. Also monitored are emergency and schedule adherence situations and exceptions in service due to delays, bunching, overloading, traffic congestion, and breakdowns.

Maintenance may wish to inform the service manager when buses break down and instantly provide the vehicle ID to the vehicle maintenance system (VMS). The full maintenance history of the vehicle and its exact location on the street can then be given to a work crew as soon as possible. Some VMS data can be used by the AVLC system to track spare vehicles (including where they are parked).

On the marketing side, on-line and off-line system access would monitor delays and service disruptions and provide this timely information in response to passenger requests and queries.

The administration section within the transit property will be able to use the historical data on driver work hours and overtime as input to their computerized timekeeping and payroll systems.

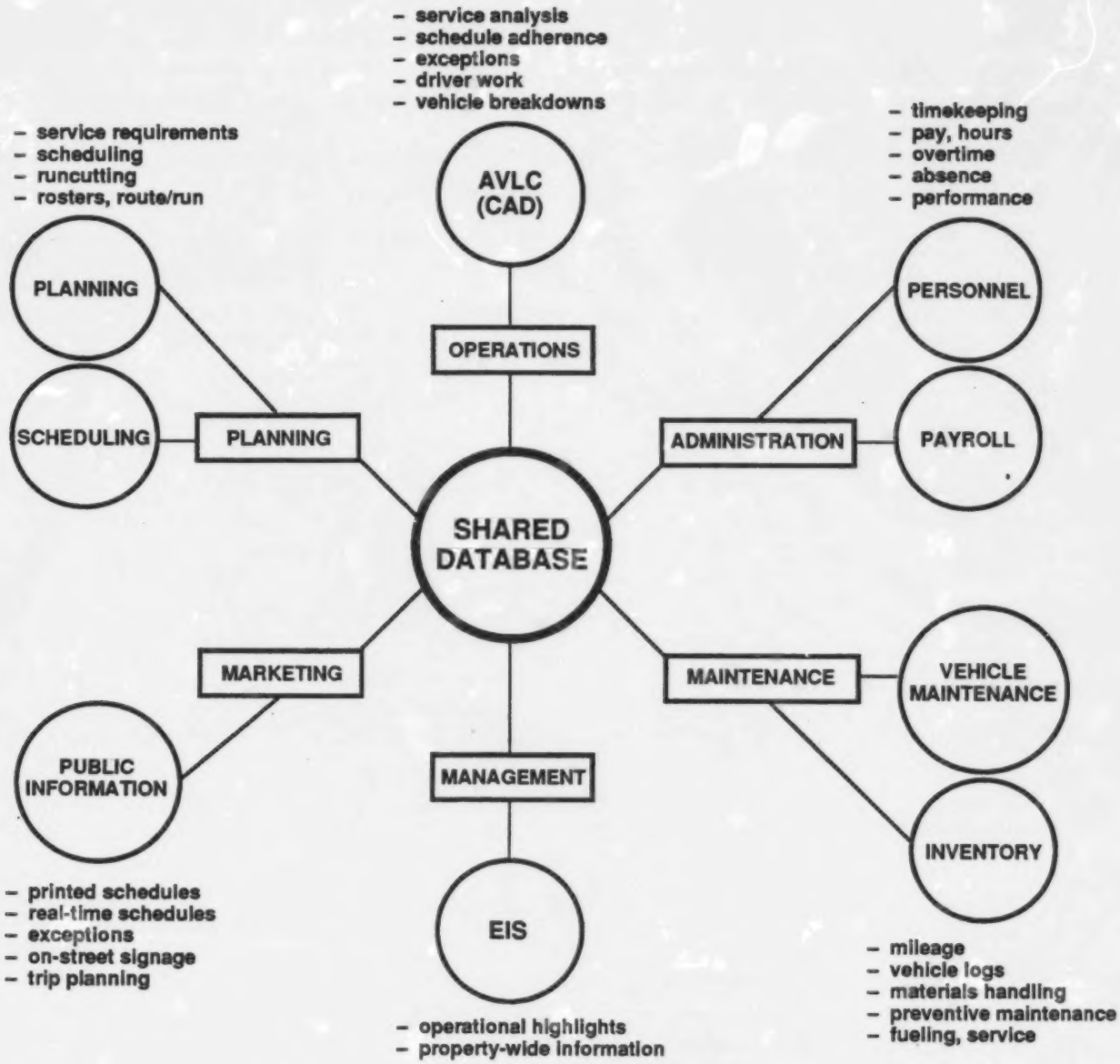

Figure 2/ Example of Central Software/Database Architecture

Finally, management will require full reporting and data input to its management information systems (EIS) on the efficiency and effectiveness of service performance. This will assist senior managers in tracking operator and fleet performance against the property's service policies.

3.8.5/ Displays

Displays are essential in any AVLC system. The system conveys and communicates real-time, stored, and historical data to controllers and dispatchers through the different types of displays. Displays may range from simple textual lists, to graphical representations or schematics, to full-blown digital electronic mapping.

The choice of screen layouts and arrangements and the type and amount of information presented can be as individual as the controller or dispatcher. For this reason a transit property must fully consider the needs of the AVLC system end users when developing display screen details for the system requirements.

While it would be impractical to describe all possible screens the AVLC system display software could support, this section highlights some of the more essential or useful features properties should consider. In the past, properties have relied on multiple display terminals, supporting split screens, to present real-time and store information to controllers and dispatchers. With the introduction of windowing technology, this can now be incorporated on a single terminal or workstation screen.

A controller, dispatcher, or supervisor station will typically require:
- a continuous display of incoming and recent driver calls;
- a continuous display of open incidents registered by the AVLC system (e.g., alarms, schedule adherence violations);
- a display of communications activities (e.g., call acknowledged);
- other screens to provide static and dynamic information, nominal and actual data, and a system user command dialogue interface.

Therefore, key display information may include, but is not limited to:

- a status area or window providing AVLC system users with data on individual vehicles and the fleet including:

  - driver initiated call requests, arranged in queues base on type and priority;
  - emergency and mechanical alarms that have been acknowledged or are being attended to;
  - schedule exception conditions of vehicles such as early, on-time, late, and very late buses.

- a general work area or command line providing a means for the controller or dispatcher to converse with the computer by typing commands and using preprogrammed function keys;

- a bus data area or window where all the current information on a single vehicle can be displayed, including:

  - route/run, vehicle ID, driver ID, operating status, and passenger count, schedule deviation, schedule adjustment in effect, and schedule deviation at last timepoint;

  - operational control and tactical information;

  - existing problems, their nature, identification of the unit(s) responding to each problem (e.g., supervisor or maintenance), and the ID of the controller, dispatcher, or supervisor handling the problem at the central control;

Note: vehicles requiring special attention could be assigned a high or very high polling priority to keep a closer watch on the vehicle's location and status

  - a comment area, accessible only by the controller, dispatcher, or supervisor initially servicing the problem, where special information could be entered for display to others watching the ongoing situation;

  - schedule information including current location and time, next layover location and estimated time of arrival and scheduled departure time from next layover.

- a general data area or window containing lists or tables of information including schedule information about individual or specified groups of vehicles, listing all vehicles in a given group according to service class, passenger load, tactical situation, status, and other user selected classes such as chartered;

- a system area or window to provide instructional information (e.g., help) about the use of the system or explicit function keys and to provide AVLC system status messages.

With these types of display screens or windows, dispatchers, controllers, and supervisors can:

- monitor the whole fleet, or any specified group of vehicles on any given route;
- call up real-time information on any AVLC equipped vehicle and locate it;
- review available information on a specified group of buses;
- generate trouble reports or update an on-line problem log;
- handle emergency and mechanical alarms.

Screens will contain text or graphics or both. For example, TTC's CIS system uses colour graphics consoles with three-colour display screens. Each of the screens represents a graphic loop display or schematic of up to three selected routes.

Each route is displayed with its buses' actual and scheduled location. The schematic provides, at a glance, a visual check on the status of several vehicles and different routes, by using their relative positions around the loop and the colour of the vehicle symbols. A third screen contains detailed information on all vehicles and routes assigned to the console.

Some properties may wish to extend the textual descriptions and the graphical representations one stage further to full electronic mapping of the property's service area. An example of an electronic map display taken from the Baltimore AVLC system is shown in Figure 3.

A municipal Geographic Information System (GIS) can provide basic street maps which include features such as:

- address matching;
- digital street network maps, scaled from 1:5 000 to 1:10 000, for on- and off-line use;
- intersection co-ordinates, blockface co-ordinates, street connections between intersection, street names, addresses at intersections;
- municipal boundaries, water features, railway and transmission lines, boundaries of significant areas, and landmarks;
- routing for transit planning, demand response service, and public information or trip planning services.

At present, there are several suppliers of digital electronic map software technology and databases. The advent of laser disk technology provides an ideal medium for storing and retrieving digitized electronic map display information.

Functionally, a required map display is selected from the stored disk in the control centre workstation or high-end microcomputer. The same computer accepts the vehicle data from the data link transmission subsystem and generates computer graphic symbols representing each vehicle. These symbols or icons are then superimposed on the displayed map and their positions updated in real-time as the moving vehicle is polled.

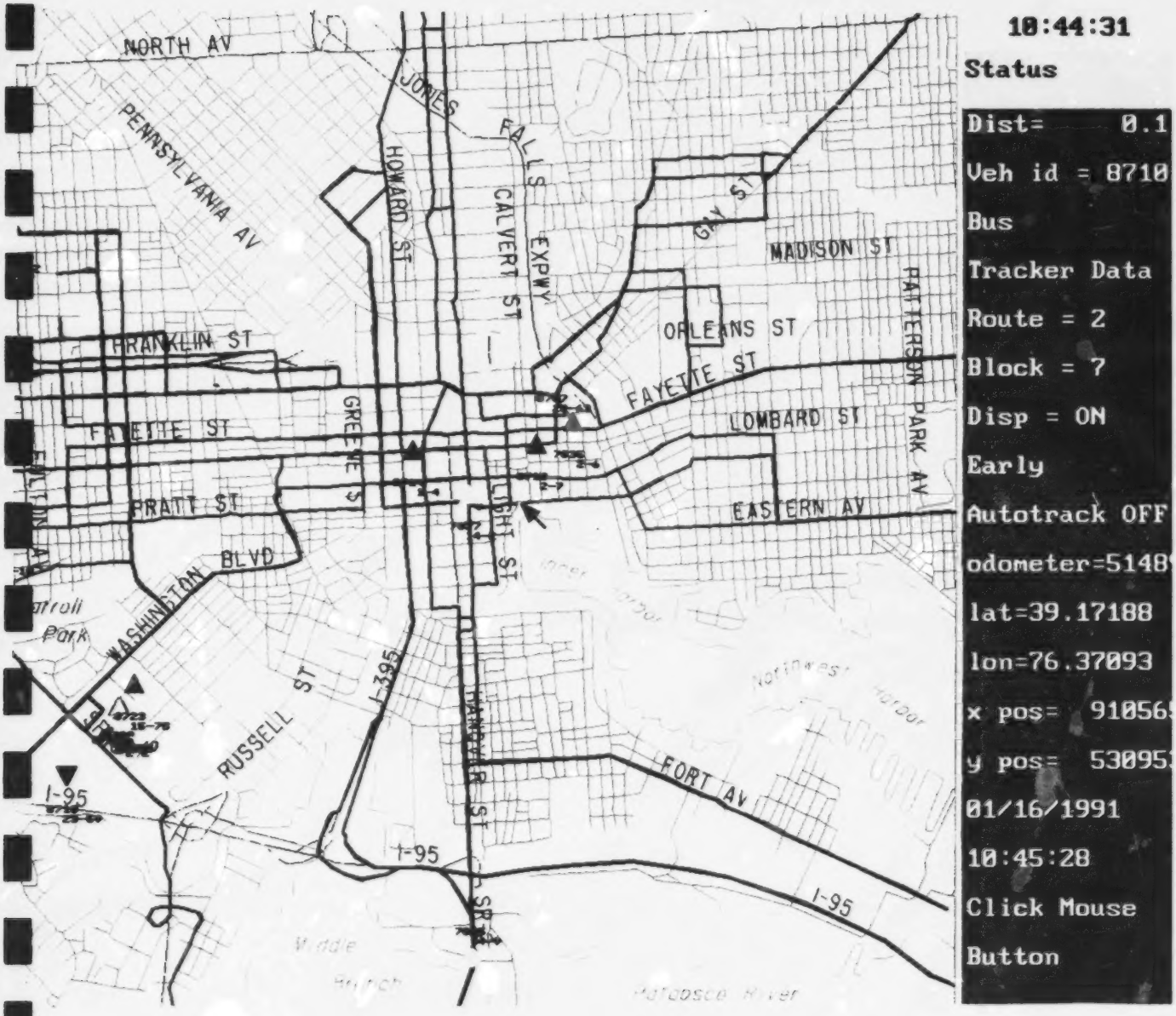

FIGURE 1/ Electronic Map Display from Baltimore's AVLC System

3.9/ Location Accuracy

The subject of AVLC system location and positioning accuracy has been researched over many years. Some AVLC systems are designed to learn as they go. These systems constantly improve the accuracy of tracking specific vehicles on specific routes by learning the inaccuracies associated with each vehicle and route. At the TTC, the system uses the average of the distances calculated based on thousands of bus passes.

Location accuracy can be broken down into three main categories: inherent, repeatable, and absolute accuracy.

Inherent Accuracy is the theoretical accuracy of the location system in use.

Repeatable Accuracy is the measure of the variation in position demonstrated by the location system when repeatedly returned to the same location along the same route.

Absolute Accuracy is the measure of the ability of the location system to identify a known position accurately.

Location accuracy may be specified in two different ways: as a *distance* from a known location (measured in metres or feet), or as a *time of passage* past a given timepoint (measured in seconds or minutes).

The distance accuracy is simple and based on where a given vehicle location should be (logical location) versus where the vehicle actually is (physical location).

The time of passage accuracy is a true measure of a vehicle's schedule adherence, because the schedule base and passage past a given timepoint in the schedule are measured in time.

An accepted accuracy for AVLC systems is ± 60 metres for distance accuracy and ± 15 seconds for passage accuracies. As stated above, the time in seconds is most critical since it is used to calculate all schedule adherence and schedule deviation information.

Lastly, two further accuracies must also be considered by those properties that employ electronic maps to aid in locating transit vehicles:

Positioning Error results when a vehicle's symbol or icon is positioned on the electronic map display based on the information received when the vehicle was last polled. Assuming the vehicle continues to move after the last poll, this results in a map positioning error that increases directly with the time between vehicle polls; and **Display Error** due to the display discrepancy between the scale of the electronic

map displayed and the scale of the vehicle symbol superimposed on the map. For example, if the screen across has a 1000-pixel resolution then each pixel on a 40-kilometre scale map represents about 40 metres. Therefore, if a vehicle is represented by a ten-pixel wide icon, the error in the displayed map position of the icon is ± 200 metres.

3.10/ Potential AVLC System Problems

A common problem with digitized map-based systems is that often the roadbed database has data that is incorrect or contains some local inaccuracies. Applications and supporting mapping software *must* have exact distances from timepoint to timepoint, in the appropriate units of measure, stored in the database.

For proper positioning accuracy, especially where map-matching is employed, every on-street deviation must be measured and entered into a database. Measuring routes, for a property with a 150-bus fleet, can take up to three person-months of work (i.e., three workers for one month). The database, once fully created, must be maintained and updated periodically.

A potential problem may occur when a bus on a fixed route moves from its original scheduled route to another newly assigned route. When this happens, driver, bus, and expected route/run start time information must also be transferred so the system can monitor and predict the schedule adherence on the new route. A problem can ocur on systems that assume all route/runs start on time. These systems are limited in their ability to transfer a late/early arrival on one route to a late/early departure on another route when the same bus is involved.

In more advanced AVLC systems, information from the original route is automatically transferred with the vehicle as it moves to the new route. This acknowledges when a vehicle will be late starting its new route. Advanced systems also acknowledge late arrival of drivers for routes. Without these functions, schedule adherence prediction at the beginning of routes can be unreliable.

Other potential design flaws include lack of end-of-run tracking and no layover time information (i.e., no separation of arrival and departure time at the end and subsequent start of a run).

3.11/ AVLC System Maintenance

All AVLC systems will have to be maintained and this may require a suitably equipped electronics shop. Some transit properties already have shops servicing their fleets' mobile radios.

Depending on the type of location system selected by the property, specialized training may be necessary, although this is not always undertaken. Alternatives include

contracting out the actual electronic repair while the property itself performs the first-line maintenance of unit removal, installation, and calibration.

Beyond the equipment maintenance is the maintenance of central computer systems, AVLC system software and interfaces, base station communications equipment and interfaces, and the databases. This can sometimes be a large amount of work for a small property that does not have the personnel in-house to perform the required services. In such cases, the importance of warranties and short, medium, and long service contracts with suppliers of the original systems and software may be required.

4/ AVLC SYSTEM IMPACT

4.1/ Overview

The introduction of AVLC to a transit property will have a direct impact on its operational and management practices. AVLC holds the promise of improving transit service and performance by helping to make timely and critical information more readily available to transit management and staff. Improvements should also help better allocate human and equipment resources due to increased timeliness and accuracy of the on-the-street information. AVLC should add to the traditional techniques of operational data collection and allow collected information to be used in real-time and off-line modes.

Real-time operational modes can provide up-to-the-second or minute representations of the fleet and transit system. Vehicle location, schedule adherence, headway maintenance, and vehicle status are examples of real-time status information. The readily available information enhances the response time to emergency situations and helps in the control of transit service under a wide range of operating conditions.

Off-line modes rely on historical data collected over time and retrieved from the system database. The data collectively provide a means to test and evaluate the existing service for efficiency and effectiveness and may be used as an input into the analysis and planning process.

4.2/ Operational Impact

Smaller Ontario transit properties typically operate with fewer vehicles per individual route than larger ones. Table 3 lists what could be a general operating schedule that a small or medium property might follow.

Peak service typically concentrates on carrying service area passengers to and from terminals, the downtown core, and major transfer points. Off-peak service tends to concentrate on moving riders to and from the downtown area, large malls, and shopping centres.

Some small Ontario properties now link scheduled bus service with a *Transcab* type of operation. Provided on demand, this service brings passengers from their homes to the closest terminal or transfer point. The service is normally unscheduled and does not operate on fixed routes.

Aside from driver and passenger safety, the biggest concern in any transit operation is the reliable adherence of its fleet to a predefined schedule. From the public and property management perspective, schedule adherence is perhaps the single most important performance indicator a property has.

Table 3/ Typical Smaller-Sized Transit Property Schedule

Time Period	Description of Service
Peak Periods	headways range from 5 to 30 minutes depending on service area and route
Off-Peak Periods	frequency of service typically drops down to about once every 30 to 60 minutes
Evenings	most evening routes typically have headways of about 60 minutes or more
Weekends/Holidays	service is drastically reduced, some properties have no Sunday or holiday service

Following the schedules, whether predefined or updated in real-time on a public information system, is needed to insure that passengers are not unduly inconvenienced for any one of the following reasons:

- the bus arrives early at a stop and then leaves early, causing riders who arrive at the stop just before the scheduled time to have to wait for the next bus;
- the bus misses a connection by arriving late at a transfer point, causing transferring riders to have to wait for the next connecting bus;
- the bus does not arrive at a scheduled stop at all because it has been short-turned, gone off-route, or the trip has been cancelled, causing riders to have to wait for the next scheduled bus.

In all the above cases, the wait time can be significant and especially frustrating for riders during off-peak periods and in inclement weather. If the missed bus is the last one of the day, it will likely cost the stranded passenger the additional expense of a taxi to get to his or her final destination. A rider's willingness to use the transit system again and confidence in the system's ability to provide proper service declines each time such an incident occurs.

The real-time AVLC mode may be used to monitor location and schedule adherence and improve the operational efficiency of each vehicle in the fleet. With vehicle location and schedule adherence information, a controller, dispatcher, or supervisor can determine what action must be taken to insure that early or late vehicles are brought back on schedule. The system should bring a controller's attention to those vehicles that have exceeded a preset schedule adherence threshold or if it is likely that two or more vehicles will not meet at a transfer point.

Drivers of the vehicles can be advised of any necessary actions to be taken while the central control monitors progress. If a trip is cancelled, the AVLC system should allow the central control to locate another vehicle as a short turn candidate. If the cancelled trip is replaced with a vehicle from another route, the system should allow supervisors to estimate when a replacement vehicle will finish its current run on its original route before moving to the start of the new route.

Transit properties will also want to use collected historical data to improve predefined schedules. Most properties presently collect and correlate schedule data manually. Some properties are now using computer scheduling systems to assist in building the required schedule and assignments (vehicles and drivers). With AVLC providing the historical data, data can be directly imported to the computerized scheduling system without any manual involvement.

Information on cancelled or missed trips may also be collected for analysis and reporting purposes. This data depicts those trips that did not start at the scheduled time, and is typically used for identifying those vehicles which did not perform their scheduled work during the reporting period. Regardless of the contents, all reports can be generated on a regular schedule, on demand, or in the future. Information can be reported selectively on a driver, a vehicle, a route/run or a fleet basis.

If a property is involved in chartered or non-scheduled services, the control centre can visually monitor a vehicle's location. In these cases, schedule adherence monitoring is not required. Controllers may also use the system to display the locations of standby vehicles and dead heading vehicles, passenger loads, and other information.

AVLC may also be used to provide useful real-time transit status information to the general riding public. The provision of accurate and up-to-date bus departure information is especially important for properties with long headway routes. With continuous monitoring of the actual on-street service and updating of bus arrival times, the probability of riders boarding the required bus as scheduled is significantly increased.

Properties will want this real-time schedule information to be provided to the travelling public in various manners. Some properties are even considering the use of cable television to provide arrival and departure information. The information could be displayed both in the home and at display stations in key terminals and shopping

malls. Other properties now favour the use of telephone operators and, most recently, computerized voice systems to issue real-time schedule information.

Finally, historical AVLC data may be used off-line for other types of analysis and reporting. For example, Sudbury Transit wishes to record the kilometres travelled by chartered or non-scheduled vehicles to determine overall use. This information will permit Sudbury Transit to determine if the amount charged for the use of its Transcab service is proper. Other properties may wish to track and report on vehicle kilometres, operating hours, and vehicle change-off problems for use in determining the maintenance requirements of vehicles.

4.3/ Organizational Impact

The introduction of AVLC to a transit property will inevitably affect the roles and responsibilities of the people in the production chain. The list of positions and departments affected to some degree includes: drivers, inspectors, controllers, dispatchers, supervisors, MIS, planning, administration, and management.

It is important in all cases that the AVLC system be viewed as a tool that will introduce new and more efficient methods of operation within the transit organization.

4.3.1/ Central and On-Street Control

The role of the on-street inspectors is a key issue that must be addressed by each individual transit property. In deciding who has ultimate control of the vehicles on the street, senior management will have to clearly distinguish between the role of the controller or dispatcher and the on-street inspector.

There may be many significant changes to the existing roles of central control personnel and on-street inspectors in most properties. Most properties have a centralized control centre that was put in place when the central radio control facilities were installed. However, procedures may have to be set up to insure that the central control has the authority it requires to implement the property's operational and service policies.

In Transit Windsor and Sudbury Transit, such procedures are presently in place. Kitchener Transit's operational control may have to be moved from the dispatcher's office in the transit building to the downtown terminal point supervisor's location after normal working hours. This is because the dispatcher's office is not staffed during off-hours and a street supervisor is always needed at the terminal point.

Once an AVLC system has been installed by a property, the central control will have all the service area's transit status information available for review. The schedule adherence and transfer meets of all the vehicles in the transit network or a particular

segment of the network can be monitored. If a particular control action is required, the drivers involved may be contacted and the situation rectified.

If a particular driver cannot be contacted by radio, the on-street inspector or supervisor must be counted on to relay the information to the driver. Occasionally, the street supervisor will call the central control when he or she notices a particular transit problem developing. Both the on-street and central control resources may be used to arrive at the control action(s) required to resolve the problem. In these instances, the street supervisor or the central control can then inform the affected driver(s).

The control centre monitoring functions require that the daily operating schedule be made available to the on-line system by the start of the day. The operating schedule is a copy of the planned schedule, provided by planning, and will be updated by the central control whenever a control action that affects or changes the schedule is taken.

Organizationally, this represents a major change in the roles of the controller, dispatcher, and planner. The controller or dispatcher must update real-time information in the system and thus be ultimately responsible for the integrity of the current day's operating schedule and driver-to-vehicle assignments. The planner will normally only be responsible for the planned schedule being correctly entered into the system.

4.3.2/ Drivers and Buses

Another area of operation that will change is the correlation of bus numbers to block numbers and drivers. This information is usually provided at the start of each run and during change-offs.

Presently, most transit properties rely on the controllers or dispatchers to write this information down on a piece of paper. AVLC systems should either fully or partially automate this task.

In some transit properties the driver must enter this information into the electronic fare box. The drivers enter their ID number, block/run number, and the start time of the run into the onboard electronic fare box. Alternatively (e.g., Transit Windsor), drivers must report the bus and route they are assigned to by pressing the appropriate button on the radio communication system.

Drivers can continue to perform these types of functions but the information entered must then be channelled into the AVLC system through an appropriate interface. Therefore, to take advantage of the current practices, an AVLC system must accept the assignment information from these types of devices. If these devices do not exist at the time the AVLC system is implemented, the AVLC system must provide its own means of collecting start of workpiece and run information.

4.3.3/ Staff Training

Properties will require staff training before, during, and after the installation of an AVLC system. The central control personnel must be made aware that AVLC provides the user with both stored and real-time information. The amount of information available for display can be overwhelming and every effort must be made to display only the relevant information.

However, some properties are already using two-way voice radio communications as part of their present operations control strategy. Where the current practice is to handle bus assignments, schedule adherence, and bus location at the central control site, the impact of any reorganization should be less.

One important note that must be considered by all properties intending to implement AVLC has to do with the staffing of the control centre controllers and dispatchers positions: *There is no substitute for experience.* Both OC Transpo and Hamilton Street Railway attest to the fact that the best control centre personnel have come from their most experienced operations and control people.

Although sophisticated computer and communications technology are incorporated into a typical AVLC system, *the system cannot duplicate the years of experience driving buses in all conditions and working as an inspector on the street.* While AVLC will assist the controller or dispatcher, it is the people in the control centre who will carry out the various control strategies to deal with the different real-life on-street problems.

The availability of large amounts of data and information also means that controllers and dispatchers will have more incidents to handle, more information to absorb, process, and disseminate, more transfer meets to supervise, and more events to monitor.

4.3.4/ Planning

The availability of historical AVLC data will also affect a property's planning functions. Manual methods of producing schedules will eventually become a thing of the past. Computerized scheduling using information from the AVLC system should become, in time, a helpful by-product. The AVLC system must provide the planners with the facilities to produce the appropriate files suitable for use by the transit property's schedule production software.

The accuracy of the data provided to the planning software depends on the integrity of the data in the AVLC system's database. For example, running time data will not be accurate if the information on detours is not entered into the system. In fact, if the information about any control action that has been taken, such as cancelled trips, is not entered into the system in a timely manner, the information displayed at the central control will be erroneous.

Some existing AVLC systems will, in certain cases, prompt controllers or dispatchers to provide the required input data before the users can proceed to take further action.

4.3.5/ Public Information

AVLC systems can provide up-to-date bus arrival and departure information to the travelling public. Most properties will eventually use some form of automated public information system.

Depending on the public information system to be interfaced with the AVLC system, the job functions of the individuals currently providing public information will most likely change. This change will vary depending on the property's existing public information system and will use on-line display systems as opposed to predefined paper schedules. On-line displays will allow more emphasis on trip planning and responding to customers' complaints rather than merely providing predefined scheduled departure information.

4.3.5.1/ Customer Complaints

The historical information stored by the AVLC system can also be used for verifying public complaints and incidents related to bus stop arrivals. STO in Hull uses stored data to verify or disprove complaints by riders as to whether a bus was late or early at arriving at a given stop. According to STO, all complaints are verified where possible. Of those verified, 80 to 85% are found to be valid, while 15 to 20% either are not valid or are inconclusive.

4.3.6/ Technical Support

The implementation of AVLC systems will require many resources in the form of people, money, hardware, and software. The need to keep the AVLC database current will be one of the greatest impacts on a transit organization. The state of the database will affect the operational environment of the entire transit information system's organization.

The individuals in the transit organization currently responsible for maintaining overall transit property data will keep their current functions but they must be trained to use the system properly and effectively.

There will be a need for an individual who is technically responsible for the overall AVLC system implementation and operation. This individual must be knowledgeable about the operation of the AVLC system, its hardware and software requirements, as well as its relationship with the other functions within the transit organization. After implementation, responsibilities will include training new operational personnel, troubleshooting hardware, software, and system problems, insuring proper data management, advising system users, and managing the system.

4.3.7/ People

AVLC will impact:

- those who use the transit system
- those who work for the transit system.

The impact of AVLC on the travelling public should include:

- improved quality of service
- shorter wait times
- more accurate and up-to-date real-time schedule information.

The service should be more reliable and the chances of missed transfers reduced. This flow-through of benefits to the property's ridership should make taking public transit more pleasurable for both the daily and occasional rider.

Experience has also shown that working conditions for both control staff and drivers should improve in the following ways:

- control staff will have the necessary tools to effectively assist them in monitoring and managing the property's fleet;
- on-street inspectors will have access to the information they need, when they need it;
- *drivers will no longer work in isolation* but become part of the overall operations and control team providing essential and reliable service.

The property's drivers and riders should feel more secure, knowing that central control can provide instant assistance in any situation (e.g., emergency, fare dispute) and can provide police with the exact location and progress of the vehicle as required.

Working conditions for other operational and planning staff should also improve. Because vehicle and driver assignments will be automated, updates should be easier. In summary, there will be less paperwork in the workplace and more on-line information at the user's fingertips.

4.4/ Net Benefits

Although transit properties have tended to implement AVLC as a tool to provide greater safety, security, and service reliability, significant operational benefits have been realized too. For smaller properties, this resulting impact can be significant, especially where capital and operating resources are scarce.

The benefits of AVLC are derived from improvements in the productivity and effectiveness of the transit operation itself. Improvements in productivity results in cost displacement benefits. Improvements in effectiveness result in value added benefits.

Cost displacement benefits are related to cost savings in vehicles, personnel, and improved operations. For example, AVLC should improve the punctuality of the service and reduce running time. The time gained may impact the number of vehicles and drivers required to provide the same level of service. This may result, depending on the number of vehicles on a route, in the saving of vehicles and drivers for that route.

A review of literature shows that AVLC systems have improved running times by 0.5% to 1.0% in some European transit properties and have provided a gain of about 1.3% in recovery times. In one case, the average wait time for all passengers has been reduced by five seconds per trip, saving the 360-bus property 3.6 vehicles the first year.

There are cases in which the benefits associated with efficiency gains cannot be easily translated into cost savings. For example, when an AVLC system saves dispatching time, it does not always mean that fewer dispatchers are required. Instead, the time the dispatcher has gained can now be put to use elsewhere. This may include handling emergencies or the provision of on-street transit personnel to deal directly with the riding public.

For managers, the availability of timely information and data is essential and will promote better operational decisions. It is difficult to measure the cost saving attributed to the outcome of better decisions. Benefits that focus on greater organizational effectiveness are often called *value added benefits.*

Value added benefits can sometimes be quantified. For example, the positive view held by the public toward the transit system, combined with an improvement in the quality of service, can boost ridership. Some European and North American properties believe that the service improvements experienced after installing AVLC have resulted in ridership increases of more than 1% in a single year. In fact, a recent study conducted by Brampton Transit forecasted an annual ridership increase of about 1% achievable through improved service and transit system performance.

There are other areas in which AVLC can produce value added benefits. Getting more relevant and timely information to transit management and planners will directly improve the level of service. Better schedules can be produced automatically and the overtime associated with vehicles returning late from their runs can be tracked with greater accuracy and control.

Finally, there are the *intangible benefits.* They come in the form of better working environments, improved response time to problems, and a fostering of better working relations between control and supervisory personnel and the on-street inspectors and drivers.

5/ AVLC SYSTEM REQUIREMENTS

5.1/ Performance Requirements

A transit property should try to obtain the highest level of AVLC system performance possible within its given set of restraints and requirements. The following list is presented as a guideline of performance requirements to assist the reader in rating various AVLC systems specifications and capabilities.

System Accuracy: An AVLC system should have a location subsystem with a high absolute and repeatable accuracy. The communications subsystem must have an extremely high chance of reception for all radio signals (data, voice, or both).

System Reliability: An AVLC system must operate reliably at all times (peak and off-peak) and within the specific area of coverage or service area, including the downtown core area of urban centres. The users must be assured of the data integrity of the system.

System Flexibility: An AVLC system must operate in all types of environments, including city core areas, suburban areas, and in any future area in which the property may operate.

System Durability/Expansion: The system must be durable, not just in the sense of current operation, but also with a view to maintaining durability as the system ages or grows and expands with the size of the transit property operation.

In-Vehicle Unit Size: The in-vehicle equipment unit size is important for system installation, positioning, maintenance, and access within the vehicle. The in-vehicle driver control head must be easily accessible by the driver and free from obstruction.

System Unit Costs: The overall cost of an AVLC system will always be affected by tradeoffs between the desired functionality versus the necessary functionality and the present versus future use. Long-term goals must always be considered when determining the maximum system cost on a per-unit, per-vehicle basis.

System Expansion: AVLC system requirements and designs should be planned with modularity in mind and an eye to the future. The AVLC system implementation must permit enhancement of system capabilities and expansion in system capacity and size.

Electromagnetic Interference and Noise: Technical specification of system parameters must always include the extent to which the system will exhibit indifference to external (e.g., power lines) and internal (e.g., florescent lights) electromagnetic interference.

Driver Input: AVLC system designers or those specifying the AVLC system requirements must always consider the extent to which the vehicles' drivers will be required to interact with the system. The question is: *will driver input be required routinely or only as an exception?*

Communications System Response Time: The time an AVLC system takes to transmit, receive, or acknowledge inbound and outbound messages (including regular and high priority transmit) between the central control and one or more vehicles is an essential parameter and *must* always be specified as part of the overall system requirements.

Electronic Map Displays: If digital electronic map displays are chosen as the vehicle location display medium for controllers, then the specifications should include:

- smallest display area (square blocks, kilometres, etc.)
- zoom in and zoom out time
- map database update capabilities
- the accuracy actual order of travel when one or more vehicles are within a minimum distance of each other.

Weak Radio Signal Handling: Methods for dealing with an intermittent or suspected loss of signal (i.e., when uncertain whether radio contact has been lost or not) must always be specified in the AVLC system requirements.

Complete Radio Signal Loss: Methods for dealing with a complete loss of signal contact with one or more vehicles, the base station, or the control centre must always be specified in the AVLC system requirements.

5.2/ Operational System Requirements

The following section presents a list of some basic system requirements. The systems are divided into two types:

- an AVLC system with features such as full schedule adherence monitoring and historical database capabilities;
- an AVL system primarily providing vehicle location only.

Each of the requirements below has been independently rated for each type of system as follows:

E = Essential or mandatory requirement
D = Desirable if possible and cost not prohibitive
O = Optional based on the discretion of the individual property
N/A = Not Applicable

Table 4/ General System

REQUIREMENT	AVLC	AVL
track a variety of vehicle types (i.e., fixed route and paratransit buses, supervisory and maintenance vehicles)	E	E
route incoming position data to a variety of systems and applications (i.e., schedule monitoring, display, paratransit dispatch, real-time public information, on-street signage)	D	N/A
interactive, real-time update of daily schedule by controllers with allowance for temporary route/schedule changes by time, day, week, month, and season	D	N/A
last known vehicle location reported if ever contact is lost	E	E
remote terminal access to central site system	D/O	D/O
central site telephone answering and patching capability	D/O	D/O
automated system start/restart procedure	E	E
central site equipment must operate in normal office environment	E	E
built-in system redundancy to prevent overall system failure due to a non-catastrophic event	E	E
stand-by power supply	O	O

Table 5/ Onboard Vehicle

REQUIREMENT	AVLC	AVL
silent alarm system capabilities	E	E
no action required by drive, no display	O	O
vehicle ID hardwired	O	O
dispatch selected secure and hands-free onboard microphones	E	E
fully functional control head and multi-line display	E/O	O
onboard interface capabilities to public address system	O	O
onboard interface to changeable message signs and electronic farebox for uploading and downloading information	O	O
self-diagnostics in mobile equipment	E	E
onboard equipment hardened to operate in the rugged urban transit environment	E	E

Table 6/ Monitoring

REQUIREMENT	AVLC	AVL
fleet wide monitoring for off-route vehicles	E	E
position information for each vehicle in fleet	E	E
update position of full fleet every 30 seconds	D	D
update position of full fleet every 60 seconds	E	E
provide vehicle position on an exception or selective basis	E	D
fixed route vehicle schedule status on a fleet-wide, demand, or exception basis	E	N/A

Table 7/ Database

REQUIREMENT	AVLC	AVL
relational database (with utilities) providing reliable high-speed data storage and retrieval	E	N/A
easy, user-friendly manual data entry and retrieval	E	N/A
automatic historical database generation	E	N/A
automated archival and backup capabilities	E	N/A
built-in selective data security capability	E	N/A

Table 8/ Reporting

REQUIREMENT	AVLC	AVL
selected vehicle equipment status and sensors	O	O
mechanical and emergency alarm sensors and indicators	O	O
reporting as per driver, vehicle, route, run, shift, etc.	E	N/A
reporting as per incidents, schedule deviation, performance, dispatcher activity	E	N/A
reporting as per mobile radio activity, alarm activity, mobile unit malfunction, system availability, and equipment availability	E	N/A
ad hoc report capability	D	N/A
record and playback of stored historical on-street events from database (i.e., replay movements of buses on a route during a certain time period showing status of each vehicle as it was in real-time)	D	N/A
colour printer for hard copies of screen map displays	D/O	D/O

Table 9/ Display

REQUIREMENT	AVLC	AVL
pull-down menus	E	D
windowing and split screens to support tabular information	E	D
vehicle's location and status shown on an electronic map display and in table or chart form	E	E
the map display incorporates a dynamic zoom capability	E	D
the map display incorporates a planning capability	E	D
high zoom magnification levels optionally display landmarks (i.e., bus stops, street names, terminals, garage, stations, other major geographical points)	E	D
the display possesses some interactive map capabilites (i.e., click on item attached to database)	E	D
individual consoles are able to operate independently	E	D
"hand-free" automatic display tracking of vehicle with emergency status	E	E
screen refresh time of map less than one second	D	D

Table 10/ Polling

REQUIREMENT	AVLE	AVL
polling air time limited and adjustable for 10% to 80%	D	D
polls require less than one second air time for complete cycle (i.e., poll out to receive response)	D	D
system automatically adjusts polling sequence to the order of arrival to account for bunching of vehicles on a given route	D	D
the system employs two separate standard polling intervals for the fleet allowing each vehicle to be assigned to either one	D	D
a third fast poll employed for emergency vehicles or special situations	D	D

Table 11/ Radio

REQUIREMENT	AVLC	AVL
separate two-way radio data and voice channels	D	D
ability to interface to existing two-way radio system	D	D
use of existing voice radio channels where possible	D	D
the system uses coded messages, where applicable, to reduce central-to-vehicle data transmission traffic	D	N/A
special handling for lost or suspect communications	E	E

Table 12/ System/Application Interfaces

REQUIREMENT	AVLC	AVL
scheduling, runcutting, rostering, time keeping, dispatching, maintenance	E	N/A
base station equipment must be capable of interfacing with the designated base radio equipment	D	D
provision of a data port to supply real-time information to a public information system and on-street signage system	E	N/A

Table 13/ Modularity

REQUIREMENT	AVLC	AVL
modular software which allows for additional features and various interfaces to other application (upgrading)	E	D
modular central hardware which allows for additional users, data storage, and processing power as required (expansion)	E	E
modular vehicle hardware which allows for different levels of sophistication ranging from no driver display to status panel to full remote data terminal (flexibility)	E	E

Table 14/ Standards

REQUIREMENT	AVLE	AVL
proven system performance	E	E
failure of a mobile data control unit does not interrupt or disable voice communications	E	E
mobile equipment meets or exceeds accepted standards for shock, vibration, humidity, dust, heat, and freezing temperatures	E	E
mobile equipment is designed to withstand exposure to direct sunlight, substantial EMI generated on transit vehicle, electrical power spikes and voltage drops, physical abuse	E	E
onboard equipment is designed to take into account the limited space available for installation on a vehicle	E	E
all AVLC/AVL system designs and configurations strongly adhere to accepted standards and practices (i.e., IEEE, ISO, CCITT, ANSI, CSA, DOC), where applicable, including the hardware and software systems architecture, communication protocols, and system, user, and graphical interfaces	E	E
maps used by vehicle location display system are created from a standard source and should allow for limited updating and maintenance by the transit property	E	E
location accuracy of up to 200 metres 95% of the time in 95% of the locations	E	E
location accuracy of up to 30 metres 99% of the time in 99% of the locations	D	D
schedule adherence accuracy to within 15 seconds	D	N/A
schedule adherence accuracy to within one minute	E	N/A

5.3/ User Requirements

This section presents to the reader the surveyed operational user requirements of the transit properties taking part in the AVLC for Small Ontario Properties study.

The properties contacted during the preparation of this report spent considerable time examining their operational control and management needs and translating these needs into a set of system requirements. These requirements form a standard against which available systems and technologies can be measured and costs derived.

The reader is cautioned that the lists presented below are not exhaustive and only form the basis for a general evaluation of alternative systems and technologies.

In the tables that follow, each system feature is accompanied by a number ranging from zero to ten (0-10). The ratings or rankings may be interpreted as follows:

- a score of 10 may be interpreted to mean that the feature is considered essential;
- a score in the range of 4 to 8 says that the feature is desirable to some degree, but its inclusion may depend on factors such as cost;
- a score of less than 4 implies that the feature is really not considered useful or needed.

The information collected from the transit properties survey has been compiled and is shown in Tables 15 to 19.

Table 15/ Operational Control and Supervisory Displays

Item	Description	Priority
A01	display the location of each bus superimposed on an electronic map of service area	10
A02	display the schedule adherence of each bus numerically or colour coded on map display	10
A03	display, on request, the location of: a) standby vehicles b) dead heading vehicles	10 7
A04	provide entry/withdrawal data on vehilces/drivers/routes at start and end of service by: a) dispatcher at garage (via keyboard) b) individual driver input (in-vehicle unit) c) other automation (portable electronic tags)	10 5 5
A05	provide a separate tabular listing of off-schedule bus IDs and assigned operators	10
A06	automatically provide real-time passenger load information	10
A07	provide an alert or early warning for possible transfer time deviations	8
A08	provide a means of displaying headways between vehicles	7
A09	provide an alarm for off-route vehicles	7
A10	provide the location of chartered and unscheduled vehicles	10
A11	provide an electronic bulletin board summarizing any service problem	7
A12	provide A01, A02, A03, A08, A09, A10 in supervisor cars	5

Table 16/ System-Generated Reports, Database

Item	Description	Priority
B01	provide reporting on schedule adherence by: day, time, stop, run, route, etc.	10
B02	provide reporting on passenger load/counts by: day, time, stop, run, route, etc.	10
B03	provide a summary report on supervisor interventions (keyed in by supervisors) by: day, time, place, type, supervisor ID, driver ID, vehicle ID, etc.	10
B04	provide for the analysis and generation of schedules based on schedule adherence data	10
B05	provide reporting on travel times between stops and timing points	8
B06	provide reporting on driver work hours	7
B07	provide reporting on vehicle operating hours and kilometres travelled	7
B08	provide a summary report on vehicle change-offs	7

Table 17/ Vehicle and Supervisory Communications

Item	Description	Priority
C01	provide for two-way voice communications	10
C02	provide for central monitoring of driver initiated status (push buttons): a) emergency b) other service-related incidents (fare dispute, RTT, PRTT, loads, etc.)	10 7
C03	provide for automatic central monitoring of vehicle status: (door, engine/transmission temperature, speed, on/off, odometer)	7
C04	provide feedback display of schedule adherence to drivers	7
C05	provide a menu of pre-defined messages sent from supervisor to driver console: (wait/do not wait for transfer, speed up/slow down, return to garage, short turn, relief on way)	5
C06	provide for vehicle-to-vehilce (i.e., driver-to-driver) communications	5

Table 18/ Public Information Systems

Item	Description	Priority
E01	provide a public phone-in system giving real-time arrivals at stops by: a) telephone operator b) computer synthesized voice	10 10
E02	provide a means of displaying real-time or expected bus stop arrival times: a) at individual stops b) at various public locations (e.g., shopping malls) c) in riders' homes (e.g., cable TV)	not rated
E03	provide expected next bus display or announcement at each stop	10
E04	provide for route advisory	4

Table 19/ Performance Specifications

Item	Description	Priority
F01	provide flexible vehicle location: changed routes, expansions, and detours	10
F02	provide vehicle locations (95%) within: a) 50 metres of real position b) 100 metres of real position	7 10
F03	provide vehicle position updates every: a) 1 to 20 seconds b) 21 to 40 seconds	7 10

6/ EXISTING SYSTEMS

6.1/ Introduction

Tables C-1 and C-2 of Appendix C provide a sample cross-section of some of the North American transit properties that have implemented, are in the process of implementing, or are considering implementing an AVL or AVLC system. The data for the two tables were collected in late 1990.

Table C-1 lists the surveyed transit properties by name, location, phone number, and contact name (where available).

Table C-2 lists the type of location system each property has chosen or is considering, the principal or prime contractor, and whether schedule adherence is as part of the AVLC system.

6.2/ Toronto, Ontario

The Toronto Transit Commission's (TTC) Communications and Information System (CIS) is among the largest and most sophisticated in the world. When fully installed at the end of 1991, the system will have cost about $37-million.

As part of CIS, TTC has equipped all of its approximately 2000 surface vehicles (i.e., buses, trolley buses, and streetcars), which operate out of three districts further divided into ten separate garage divisions. Each division has its own control centre, which monitors and controls the vehicles operating on the routes within its service area. The divisions are also responsible any on-street supervision. TTC's main central control centre oversees the overall CIS system and fleet performance.

The CIS system functionality includes: schedule adherence, real-time service adjustments around traffic delays, market research capabilities for long-range scheduling, and fewer service gaps. The system provides fleet operators with advance information on traffic conditions, support from divisional control in the event of fare disputes, and faster response to mechanical problems and emergencies.

Onboard each TTC vehicle is a Transit Universal Microprocessor (TRUMP). The unit contains a microcomputer, UHF radio, cellar phone, handset, microphone, driver display screen, and user keypad. By using special buttons, the driver can supply his or her control centre with several different types of information. Messages include information on passenger load and requests for help in the event of a fare dispute or emergencies such as ill passengers or crimes in progress. Each vehicle has a public address system available to both the operator and the control centre.

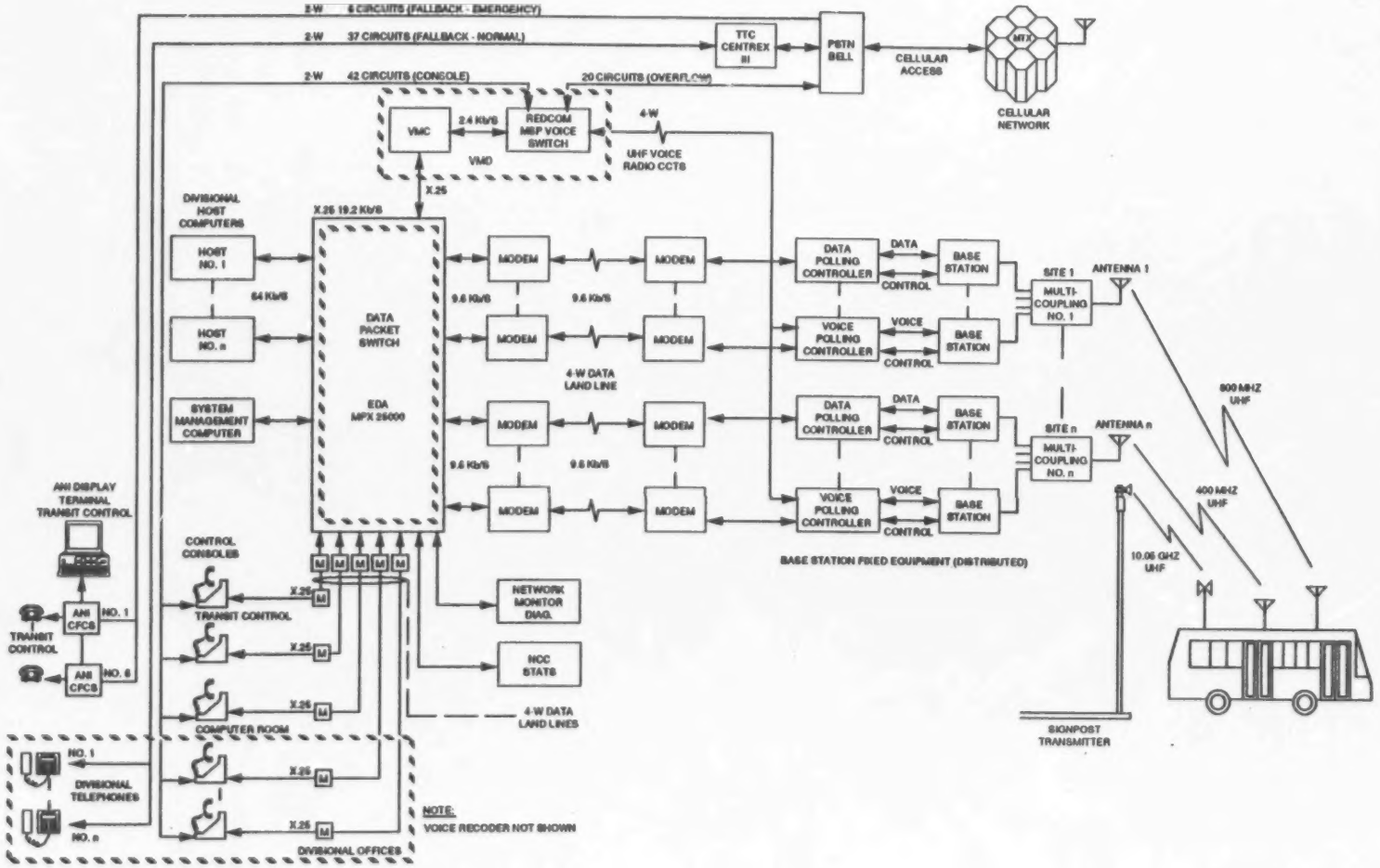

Figure 4/ Schematic of TTC's CIS

Inspectors at each Division Control Centre monitor three-colour screens displaying the scheduled and actual locations of every vehicle assigned to them. The displays are both graphical (i.e., schematic route display) and textual tables and charts. All vehicles on all routes being monitored by a division are covered. Inspectors also have a keyboard, CIS handset, and conventional telephone for communicating with the vehicles through either text messages or voice communications.

Each vehicle in the surface fleet is polled or contacted approximately every 20 seconds, or less, by 32 radio-based stations to exchange information, including location and schedule adherence. The centrally located computers compare the vehicle's position with its schedule. The difference is displayed both on the inspector's monitor and on the operator's display screen, onboard the bus or streetcar. Inspectors also have the option of communicating with either one vehicle or the entire fleet.

Figure 4 shows a high-level schematic diagram of the TTC's CIS system.

6.3/ Hamilton, Ontario

Hamilton Street Railway Company (HSR) operates about 284 buses serving the Regional Municipality of Hamilton-Wentworth. All vehicles are equipped with AVLC equipment. Radio communications operates on four channels: one data, two controller/driver voice, and one reserved supervisor/controller voice.

The concept of HSR's AVLC system originated from a study conducted in 1979. The completed system was a fully implemented system in 1991. Throughout the 1980s, various portions and phases of the system were installed and upgraded, including a pilot system in 1987. Following the pilot installation, the years 1988 through 1990 were spent ironing out all the problems associated with the design, development, and implementation of a custom system. Major hurdles overcome included solving the problem of odometer and power supply failures. Live tracking began in May 1990 and full fleet tracking has been underway since the spring/summer of 1991.

HSR AVLC system uses a signpost/odometer-based tracking system. The system basically operates as a dead-reckoning-based system corrected periodically by signposts. The properties 37 routes are covered completely using 60 beacons. Aside from the occasional tracking aberration in the host software, the system is extremely accurate.

For example, on HSR's King Route, five signposts cover the entire 20-kilometre run. Routine bus positions corrections are typically less than ten meters at each signpost location along the route. On other routes, corrections are generally run between 20 to 30 metres, mainly due to route calibration and vehicles weaving through traffic.

Functionally, the HSR system provides:

- centralized route supervision
- two-way digital radio communication with all vehicles
- real-time updates of actual position
- monitoring of schedule adherence
- mobile assignment of operators to buses
- automatic priority queuing of incoming calls from operators
- information for planning purposes
- management reports

The onboard vehicle equipment consists of an AVLC logic unit, keypad, display, radio, signpost receiver, odometer sensor and a silent alarm. The radio is used for both voice and data communications. The LCD display confirms operator keypushes and shows current time, schedule adherence, and messages from control.

The radios, base stations, and consoles are from Motorola. The logic units, keypad, displays, and odometer are from RMS (now Glenayre/RMS). The signposts and receiver are from Electrocom.

HSR is currently developing reports that highlight on-street schedule adherence problems. One interesting management issue at HSR concerns monitoring the schedule versus the driving conditions.

Normally, operators are given ample time to drive a given route. During off-peak hours, operators must drive slower than the actual road conditions in order to keep on schedule. Operators typically drive to actual conditions and therefore run hot (i.e., ahead of schedule) and get a longer break at during layover at the end of the line. The controllers believe they should call the offending operators and tell them to slow down and maintain schedule. The scheduling department wants the drivers to drive to the actual road conditions so they can use the AVLC system to collect data to justify changing the schedule to decrease running times during the evening.

Currently, HSR is working on resolving the following issues. In some cases, a solution has been determined but the software changes have bot yet been made.

end of line tracking: if a driver drives beyond the end of the line, AVLC will indicate that the driver has started his return trip well ahead of schedule

layover data collection: AVLC records schedule deviation and time only once at the end of the line, not both arrival and departure times

slow polling rate: (i.e., buses/per minute) this results in schedule adherence and position data updating every 80 seconds and as a result, schedule deviation information tends to be smoothed or averaged

AVLC hardware: over the past three months, 3 to 6% of the active fleet is not able to track correctly for various reasons. Failed equipment is repaired at a reasonable rate

route changes: since it takes longer to implement a change than the previous manual-send-a-note-to-the-dispatcher method, detours are not reflected in the schedule. As a result, tracking and schedule adherence data may not be valid in the area of the detour. In the event of a significant route change, it may require recalibration (i.e., measuring the route and entering the data into the AVLC database)

communications system: the acceptance of this portion has been excellent; reduced chatter on voice channels and the silent alarm has provided additional security and support for operators

tracking/scheduling adherence: this portion of the system has technically operated as designed but controllers are not consistent in use of information provided nor in the way they deal with drivers when schedule adherence problems are detected by the system.

6.4/ Hull, Quebec

The Société de Transport de L'Outaouais (STO) in Hull, Quebec uses the SAGEPAS automated bus fleet management system for real-time monitoring and control of its fleet. SAGEPAS also interfaces with INFOBUS, an automatic telephone information service providing the property's ridership with telephone access to real-time bus arrival information.

At present, the SAGEPAS system provides the STO with:

- communication between the operations centre and vehicles
- information on the vehicle location
- information on passenger loading
- assistance in trip control
- early warning of mechanical bus problems on route.

STO compiles and stores all historical AVLC data in a database. The system saves approximately 27 000 records per day. At present, STO is developing an Executive Information System (EIS) application package to interface with the AVLC database. The EIS system will provide senior management with graphical reports on the property's key operations.

The AVLC system is made up of in-vehicle microprocessor-based data control units (Gandalf Technologies), mapping software (Giro), language translation for screen displays, and other interface software. Other equipment includes: vehicle antennas, two-way data/voice radios, electronic signposts, transmission odometer hookups,

loudspeakers, treadle mats, base unit and transceiver, control centre consoles, voice recorder, central computer, voice response units, and bus stop signs.

The vehicle's driver control heads contain displays providing the time of day (transmitted with each message from the central site) and an early/late indicator (± minutes). The data control unit is equipped with a handset, loudspeaker, covert emergency alarm switch, and six LED indicators on the control panel. The status LEDs indicate power-on, reception, transmission, confirmation, call, and retransmissions.

The data control unit also monitors mechanical alarms including: engine temperature, oil pressure, transmission fluid, and air pressure. A transmission odometer is connected to the data control unit and provides the pulses used to calculate the distance the vehicle has travelled between signposts. The odometer sensor is mounted on the transmission hub and is mechanically connected to the wheels.

Eighteen proximity signposts are installed at strategic locations along the routes of the service area. Each bus, on average, passes at least two signposts on every run. The electronic beacons radiate over a radius of approximately 60 to 90 metres every two seconds.

When an onboard unit receives a signpost signal, it informs the central site on the next poll. This allows the central site to locate the vehicle exactly and update its position accordingly. A new vehicle location is calculated using this new reference point.

The central processor is manufactured by Prime Computers. The central system uses four channels for communications: data, voice, maintenance, and standby. The connection between the remote base station unit, containing the transceiving equipment, and the control centre is via land-lines. The control centre is equipped with two identical stations made up of a display, keyboard, and the communication equipment.

The type of information displayed along the top third of the display screen is as follows:
- command entry and edit field
- time indicator (same time transmitted during poll to buses)
- system command response field
- system messages area
- regular and priority calls displayed (10 queued)
- emergency events (5 displayed, 10 queued)
- mechanical alarms (5 displayed, 10 queued).

The general work area, in the middle of the display screen, shows reports and schedule information on a selected bus. Bus position is shown as a decimal number of kilometres (e.g., 2.3 kilometres) from a given signpost ID. Also displayed is the previous signpost passed and the next stop according to the schedule information preloaded into the database for each route/run combination.

Driver ID and schedule adherence in minutes (e.g., ±3 minutes) is also provided. The controller can qualify the display by asking the system to display, for example, all buses or route/runs where a vehicle is off schedule by more than a certain number of minutes.

When a route is displayed, all buses on that route are displayed. A graphic representation or schematic of the route can also be displayed showing the relative position of each vehicle on the route represented by its corresponding run number. Off-schedule vehicles are displayed with a rectangle around the run number.

Below the schematic is a tabular list of all runs for the route as well as direction, bus number, driver ID, and status for each run number.

If only a particular run is chosen, that too is displayed with schematic and data listed below including: bus number, driver ID, direction, status (schedule), alarms, passengers (where applicable), last signpost (signpost ID and distance from it), previous signpost passed, next stop, and next indicator.

Incoming radio messages are indicated by a listing of their arrival in one of three queues displayed on the controller's screen. Each queue indicates the message time, the bus number, the route/run combination, the driver ID, and type of call (i.e., emergency, mechanical, regular, or priority).

6.5/ Champaign-Urbana, Illinois

The Champaign-Urbana Mass Transit District of Illinois utilizes a simple LORAN-C based AVL system. The system indicates the position of the property's transit vehicles along each route but provides little other information. The radio system has one data channel and one voice channel. The system is configured such that the vehicle's data channel is always open until either the driver lifts up his or her phone to talk to the central control or the central control calls the driver.

At the central site, a display terminal shows each polled vehicle and its route number. Routes are displayed in different colours but there is no indication as to the vehicle's schedule adherence. The controller must look at the screen and manually determine if the bus is on time or not. This requires the controller to have extensive knowledge and control experience within the property's service area.

Champaign-Urbana often uses the system to assist drivers at transfer points to locate the other bus. The screen can be zoomed in and out to different scales. Lower level scales display service area street names. As each bus is polled, its new location is automatically updated on the electronic map display. The system also has a silent alarm feature.

The in-vehicle LORAN-C receivers have caused few problems (three to four malfunctions per year). Through experience, it was found that the fluorescent tubes on the buses required shielding to eliminate interference with the LORAN-C receivers.

The electronic map of the service area does not always show the buses on streets. The accuracy of the system is supposed to be 30 to 50 metres, but it does not appear to be this good. Urbana is completely flat with few obstacles to cause distortion in the LORAN signals; this system would probably display more difficulties in a more hilly region. Problems are also noted when a bus turns a corner.

With no schedule information (scheduling is not computerized), the usefulness of the system is limited. No reports are produced for the planning department. The polling speed is quite slow considering the small number of buses and could be a hinderance to a larger property. Any updates of the base map or route changes must be done by the company that installed the system.

6.6/ Ann Arbor, Michigan

The Ann Arbor Transportation Authority of Michigan is utilizing a dead-reckoning-based system, in conjunction with a map-matching system originally developed for police and ambulance use.

Each bus has an in-vehicle data control unit with a cassette tape that has a digitized ETAK map of the service area stored on it. A metal strip is located on the front left tire with sensors to determine the distance the vehicle has travelled. There is also a compass onboard.

Each morning, the route a bus will be on is input into the computer using a PC-based system. As the bus follows this route, it determines where it is and sends the information back to the central control, which then plots the vehicle's location on a display. To keep the bus location fairly accurate, beacons or signposts are located at the garage facility and at the downtown terminal to correct the bus location. Most buses pass one of these points at least every couple of hours.

As each bus is polled, it is updated on the central display terminal. Each bus is displayed with its route name and bus number. Colour coding is used to indicate if the bus is early, on time, late 5-10 minutes, or late 10 minutes or more. If a bus is not tracking properly it is shown in another colour.

A map-matching feature corrects any errors and puts the bus on the streets along its route. If the bus goes too far off its designated route, a warning appears. The system also supports an in-vehicle silent alarm feature.

The display terminal shows different levels of detail on streets and other features, including: regional roads, gravel roads, political and geographical boundaries, and

landmarks. The ETAK map uses geographical positions (i.e., longitude and latitude) as a base. There is a zoom-in capability that allows users' views that range from any section of the county (70 x 70 kilometres) to several square blocks. Street names do not appear on the map without being asked for. Special views can be preset, such as downtown or some other area where frequent detailed viewing will be warranted.

Routes are not displayed on the screen. A digitizer is used for cursor movements on the screen. A second display terminal is used for updating information and so on. All of the buses can be displayed here with specific information about their location and exact time off-schedule as well as a number of maintenance functions. One interesting system function is a screen on which a desired destination is entered and the routes that pass it are listed.

If any changes to the base map are warranted, the supplier does this. Route changes can be done by the transit agency. Changes can typically be implemented within 48 hours of the decision to change.

The system can produce a number of reports. Schedule adherence reports can be generated for drivers, routes, time periods, etc. A technician from the supplier comes each night to check the system and recalibrates any buses that appear to be having odometer problems. Recently, there have been a number of changes. Improved software and new radios were to be installed and the tape drives on the buses and other components, which have not held up well in the tough transit environment, need upgrading. The radios for the AVLC are separate from those used for voice communications.

6.7/ Baltimore, Maryland

The Mass Transit Administration of Maryland has installed a 50-bus LORAN-C, odometer-based AVLC system as the first step in outfitting its Baltimore fleet. The project first started in 1988 with the preparation of a performance specification. Based on the responses to Baltimore's request for proposal, Westinghouse was awarded the prime contract. Some of the sub-contracts awarded by Westinghouse included:

- Teleride-Sage Ltd. (TSL) developed the central software,
- Glenayre/RMS provided the in-vehicle equipment,
- General Electric provided the radios and base station equipment,
- Harris supplied the microwave links between base stations,
- Mobile Electronic Tracking Systems (METS) provide the LORAN-C receivers and the mapping and tracking software.

The LORAN-C system installed operates differentially by applying a reference time difference (TD) at the central site to each TD sent from the vehicles. The system combines the technologies of LORAN-C, odometer sensors, radio and Computer-Aided Dispatch (CAD) to track the AVLC-equipped buses. A vehicle's location and

status are displayed to the dispatcher. The dispatcher can locate the bus on a computer-generated map display of the greater Baltimore area.

Onboard equipment installed on each test bus consists of a driver display unit, a radio microphone, data/voice digital radio, microcomputer system, LORAN-C receiver, and antenna. The driver display unit provides a synchronized clock and schedule adherence updates. The driver unit has a pad with sixteen function keys, a two-line and a 40-character LCD display. There are no status lights, as the system uses pre-assigned messages to communicate with the driver. Also equipped on the vehicles are interior and exterior public address systems and a stealth microphone for emergencies. The bus's LORAN-C receiver can locate the bus to within one city block (±45 metres).

The central site system consists of two dispatch stations. Each station has two consoles, one for the computer-generated map and the other for computer-aided dispatch-generated incident reports. The mapping software provides a geographic display, address matching, bus route display, route stops and timepoint displays, and pictorial status of bus and off-route bus tracking.

The CAD software provides tabular display of incidents, dynamic monitoring of bus performance against schedule, access to voice channel, and a paperless logging of incidents. The AVL/CAD system collects and stores all fleet and bus performance data. This information is then used to generate route and schedule adherence reports, incident reports and dispatcher activity reports.

The communications system operates with two towers supporting nine channels, three of which are for data. When a driver powers on a vehicle unit, only the driver ID and route/run block are required.

The entire 50-bus test fleet is being polled at a rate of once every 20 seconds. The full system is expected to poll the entire fleet (900 fixed, 40 demand, 4 supervisor and maintenance) once every minute.

6.8/ The European Experience

This section briefly discusses AVLC systems implemented in Germany, France, Switzerland, and Ireland. Descriptions have intentionally been kept short and mainly highlight the location technology and controller console displays.

6.8.1/ Hannover, Germany

In Germany, AVLC systems for public transportation have been aimed at improving the information standard on current operating conditions. The systems tend to focus on offering efficient ways of spotting and eliminating service deviations. German practical experience in AVL and AVLC systems has been gained since the sixties.

In Hannover (Hannoversche Verkehrsbetriebe AG ÜSTRA), the AVLC system is used for light-rail, streetcar, and fixed route and demand bus transit. The system has been designed to be highly flexible and uses a modular structure for hardware and software. Most important, however, is the benefit of low capital expenditure gained by the standardization of the AVLC system hardware and software components according to the operational requirements of the *German Verband Öffentlicher Verkehrsbetriebe* (VOV).

The AVLC system was designed to monitor current operating conditions and detect and eliminate operational problems. The system uses signposts and information on regular stops to detect schedule deviations. Vehicle location is transmitted back to the central control, where a computer compares the actual and scheduled stop time to determine if the bus is on time. The system is also used to assign transit vehicles priority at traffic lights and to provide the ridership with up-to-date operating conditions.

6.8.2/ Strasbourg/Angoulême, France

The transit properties of Strasbourg (Compagnie des Transports Strasbourgeois CTS) and Angoulême (Soc. d'Amenagement et d'Economie Mixte pour les Transports en Commun du Grand Angoulême SIGA), in France, installed AVLC systems several years ago. These systems use dead reckoning to provide vehicle location. The properties' fleets are monitored by counting the number of wheel revolutions and detecting door openings at regular stops. Position information is transmitted by data radio channel to the central command post.

Vehicles are polled every ten seconds and the system is accurate to within about 10 to 20 metres. Onboard functionality includes normal and urgent calls, two-minute schedule adherence indicator, and alarms. At the central site, a visual representation of the service operation, schedules, and alarms are synoptically displayed on a console. The central command computer calculates the time the vehicle is ahead or behind schedule, enters the information on the screen and sends it to the associated bus. Historically, information is kept on alarms and statistics on performance, time between stations, and routes.

6.8.3/ Zürich, Switzerland

The Zürich system (Verkehrsbetriebe der Stadt Zürich VBZ) uses a signpost-based system, with 130 signposts spaced 2 to 5 kilometres apart, to provide vehicle location. Detailed vehicle location between signposts is derived by counting the wheel revolutions of the vehicle as it moves.

All location data is transmitted to the central site every 15 seconds. The accuracy of the system is approximately 20 metres. Driver displays indicate schedule deviation, order to stop or proceed, warnings, and an order to transmit passenger load.

A central site supervisor console can display three different types of screens:

- a status field with messages from all vehicles;
- lists of tables containing all vehicles on a route including time deviation, vehicle location, and spare time used to compensate for delays;
- a colour display showing the nominal and actual state of the routes, the maximum deviation of the time table and internals, and a network diagram of the service area.

6.8.4/ Dublin, Ireland

The Dublin system (Coras Iompair Eireann, Dublin City Services CIE) must be initiated by the driver at each terminal. The vehicle's location is updated by odometer input and the position is corrected at selected points using infrared signpost beacons. Vehicle location is transmitted to the central site every 45 seconds. The accuracy of the system was not available at the time of this writing.

7/ AVLC VENDOR UPDATE

This section provides a cross-sectional overview of the North American AVLC vendor marketplace. This information was collected in the spring of 1991 and may have changed to some degree by the time this report is published. Vendors are continually forming and dissolving strategic alliances as they respond to new requests for proposals from North American transit properties.

AVLC system and component cost information is listed, where available. Prices are shown in U.S. or Canadian dollars, as indicated, and are approximate and subject to change without notice. The contact names and telephone numbers in Appendix D allow the reader to request more detailed information if desired.

7.1/ Bell Radio Communications

Bell Radio Communications (formerly National Mobile Radio Communications) initially became involved in the AVLC marketplace through its experience with the Toronto Transit Commission (TTC) and Hamilton Street Railway (HSR) AVL projects. Using the credibility of the Bell name, their strategic alliance with Glenayre/RMS, and their past AVLC system experience, Bell Radio will continue to participate in future North American AVLC projects.

Bell Radio Communications provided the following equipment for the TTC's CIS-AVLC system:

- the 10-site, 42-channel voice and data radio frequency communications network;
- 2350 Transit Universal Microprocessor (TRUMP) units installed on the TTC's entire surface fleet of buses and street cars;
- the voice message switch network to route voice communications to and from vehicles to the appropriate Division Control Centre console position;
- the packet data switch network to route data messages to and from vehicles to the appropriate Division Control Centre console position.

Bell Radio estimates cost of the data control unit, driver control head and central software to be approximately $5000 on a per-vehicle basis, based on a 200-vehicle fleet.

The company believes its expertise in radio frequency networks and base stations, project management, engineering, and systems integration can be leveraged into a prime contractor's role in the delivery of turnkey AVLC solutions for transit.

7.2/ ETAK

ETAK has not had a strong presence in the transit AVLC systems marketplace since the implementation of a dead-reckoning-based system, assisted by map-matching, in

Ann Arbor, Michigan. The company has been intensely involved in the production of electronic map display software and geographical databases, with an emphasis on data and tools for building map displays. ETAK has made several key AVL installations in the emergency dispatch area including the Los Angeles City Fire Department and the Albuquerque Ambulance in New Mexico

The company views itself as a specialist in navigation systems, and does not deliver turnkey AVLC systems for transit. ETAK would play a sub-contractor's role in the implementation of any transit AVLC systems, relying on other companies to provide the central software, radios, and systems integration.

ETAK's current navigation system consists of a dead-reckoning-based system from a strategic alliance with manufacturer Robert Bosch. The unit incorporates ETAK's compact disk technology containing a digital map used by the onboard map-matching software.

The central site workstations can display vehicle location on a base map along with extras such as landmarks and boundaries. There is, however, no schedule adherence functionality. The workstation's platforms are either a 386-based machine running XENIX or a PS/2 machine running AIX (IBM's version of XENIX). The programmers tool kit uses C-language library routines.

Costs (in U.S. dollars) are approximately:

Vehicle Components	
Travel Pilot	$2495
Compact Disk (digital map)	$ 500
Base Station Components	
Geocoder Workstation	$5000
Base Map Display	$2000 to $5000 (size dependent)
Remote Access Interface	$4000
Developer Components	
Map Access Tools	$2000

7.3/ Fishbach and Moore Global Communications (F & M)

Five to ten years ago, F & M Global Communications was on the leading edge of AVLC technology and was the prime supplier of equipment to Halifax, Quebec City, Hull, Kansas City, Norfolk, and Fort Worth. On these projects the company brought together the necessary pieces to develop complete stand-alone AVL systems.

Today, F & M corporate policy has removed the company from the integration side of the business, and, at least temporarily, the company will not be offering turnkey AVLC

systems solutions. The company, therefore, is only pursuing a sub-contractor's role in the transit AVLC marketplace.

F & M continues to supply hardware and software for Automatic Vehicle Monitoring (AVM) systems and communications systems management. This includes in-vehicle driver control heads and logic units, signpost beacons, and low-power signpost receivers. The company does not have any central software to perform AVLC functions such as schedule adherence.

7.4/ Gandalf Mobile Systems, Gandalf Technologies (GMSI)

Gandalf Mobile Systems Inc. (GMSI) has been established by Gandalf Technologies (Ottawa) to target the international communications market. GMSI will globally market integrated dispatch systems to the courier, taxi, and trucking industries. The dispatch systems will be provided on public and GMSI's private radio networks.

In the past Gandalf has successfully implemented AVL systems in Hull and Halifax, providing the in-vehicle and communications interface hardware. Presently, the company is not involved in the transit marketplace. GMSI would want to play a prime-contractor's role in providing turnkey transit AVLC system if supplying AVLC systems to the transit industry were to become a priority again.

7.5/ General Railway Signal (GRS)

VIA, the transit property for San Antonio, Texas, has been operating the GRS TransitMaster signpost-based system successfully for several years. The system uses radio signposts throughout the property's service area, with signpost receiver and odometer and door opening sensors onboard the vehicle. Other projects included Syracuse and Ann Arbor.

We are informed that GRS is now out of the transit AVLC business, with the division that designed and implemented VIA's system now focusing exclusively on electronic tag-based systems primarily for rail, security, parking control, and toll lanes.

7.6/ Glenayre/RMS

RMS became involved in the transit data communications market in 1976. The company originally developed its expertise by supplying control and radio frequency communication systems for industrial applications.

In 1990, Glenayre Electronics, a supplier of voice and data communication products and systems, purchased RMS Industrial Controls, thus forming Glenayre/RMS. The new company possesses its own in-house manufacturing, marketing, sales, operations, engineering, quality assurance, and administrative staff.

On past transit AVLC projects (e.g., TTC, HSR, Baltimore), Glenayre/RMS has operated in a sub-contractor's role, primarily supplying onboard vehicle hardware, software, and radio controllers. As noted previously, the company has formed a strategic alliance with Bell Radio Communications.

Glenayre/RMS has stated that the company's strategy and focus is to become the predominant supplier of high-end transit communication products and systems in North America. The alliance with Bell, the company's in-house capabilities, past transit AVLC experience, and the resources of its corporate parent, Glenayre Electronics, are playing a role in support of its goals. Glenayre/RMS should be able to provide both AVLC products and complete turnkey systems to North American transit properties on future projects.

Recently, the company has been awarded several major AVLC projects gaining it recognition as a prime supplier of turnkey systems. Recent prime contracts include Louisville, Kentucky and Springfield, Massachusetts.

One final note: the company is now moving away from supporting strictly signpost technology. Glenayre/RMS has plans to interface its data control unit with other location technologies such as LORAN-C, GPS, and dead-reckoning-based systems.

7.7/ II Morrow

Several years ago, II Morrow installed two transit AVL systems in Champaign-Urbana and Sheboygan. To date, the company has installed over two dozen AVL systems for all types of fleets, from transit, to emergency response, to trucking. While the transit systems II Morrow has produced provide vehicle location and a map display, they do not monitor fleet schedule adherence.

To date, II Morrow still does not have an off-the-shelf system with schedule adherence capabilities. Therefore, II Morrow cannot provide a turnkey transit AVLC system without involving a third party to develop or integrate its transit application software into the company's existing AVL system. This implies that the company would have to assume a sub-contractor's role on any full-scale transit AVLC projects.

The II Morrow AVL system does support general dispatching operations using a differential LORAN-C system to locate fleet vehicles. A typical off-the-shelf II Morrow system would have approximate cost (in U.S. dollars) of:

LORAN-C Unit (radio interface)	$1 580
LORAN-C Antenna (pre-amp)	$ 500
Driver Display (20 button/4 line)	$ 390
Filter (per florescent light)	$ 60
Base Radio Interface	$4 000
PC-based Workstation	$5 000
Tracking and Mapping Software	$1 000 to $11 000 (size dependant)

7.8/ LocUS

LocUS has developed what it believes to be the next generation of LORAN-C receiver. The company is not in the AVLC business, but has the capability to deliver this location technology.

Presently, LocUS is supplying marine radiobeacon modulators and receivers (for differential GPS operations) to Magnavox under an exclusive OEM agreement. This combined location technology expertise places LocUS in the sub-contractor category in terms of supplying components or technology for a turnkey transit AVLC system.

Under contract to the U.S. Coast Guard, the company is now developing a very high performance LORAN monitoring receiver based on its patented technology. A parallel effort will lead to a highly integrated, single board AVL receiver. According to Lieutenant Commander Douglas Taggart of the United States Coast Guard, the prototype LocUS LORAN-C receiver that was tested by the Coast Guard "is the best commercial receiver [he has] seen to date."

When the product becomes a single board system, the estimated cost should drop to less than $700 Canadian dollars. Prices could be lower, based on large quantities of scale manufacturing. The first production boards are expected to be available in the second quarter, 1992.

7.9/ Magnavox

While Magnavox is not in the transit AVLC business, the company has been included in this section because of its capability to deliver various location technologies. Specifically of interest is the company's GPS receiver technology. This technological capability places Magnavox in the sub-contractor category in terms of supplying components or technology for a turnkey transit AVLC system.

The Magnavox GPS receivers can track up to six satellites in parallel. The Municipality of Metropolitan Toronto, Department of Ambulance Services, in conjunction with Magnavox's subsidiary NAV-COM, has been experimenting with a hybrid dead-reckoning/GPS-based system to provide vehicle location for Metro Ambulance's fleet of emergency response vehicles.

Costs (in Canadian dollars) of the limited (first) production hybrid systems are about $7000 complete with differential six-channel GPS receiver, dead-reckoning equipment, and packaging. Cabling and mounting hardware is estimated at $50 to $100.

Current costs for Magnavox's six-channel GPS receivers are:

MX4200 Off-The-Shelf Series	
Standard	$3200 (U.S.)
Differential	$4700 (U.S.)
MX7100 Enhanced Differential Series	
Two-Board Set	$5500 (U.S.)
In Chassis (enclosed)	$6250 (U.S.)
GPS Engine	
Embedded Single Board	$ 500 (U.S.) (quantity 100)
GPS Engine – Turbo	
Embedded Single Board with differential, time recover, extended temperature range	$2000 (U.S.) (quantity 100)

To date, Magnavox has delivered over 6000 GPS receivers since 1990, allowing for significant OEM discounting.

7.10/ Marcor

Marcor is a relatively young company running headlong in the development of a low-cost, high-reliability GPS receiver. Marcor's GPS receiver, available only as a prototype right now, can track up to eight GPS satellites simultaneously, selecting the best three for calculating a vehicle's position.

First production units are expected to be available for evaluation in July 1991, with full production expected to begin in September 1991. The cost of the units is projected to be around $550 (U.S.) in thousand-lot quantities.

Presently the company is limited to a sub-contractor's role, but Marcor has indicated plans to build itself into a major supplier and prime contractor in the transit AVLC marketplace providing everything from radios, to GPS receivers, to central software.

7.11/ Metropolitan Authority, City of Halifax

The Metro Authority's GOTIME system has been operating successfully with its 168-bus fleet on 48 routes within the greater Halifax area for several years. The system provides two-way data and voice communications, vehicle location to within 100 metres, operational information on vehicle performance, and public access to transit schedule information.

The City of Halifax has indicated to MTO that it would be willing to supply its central software to Ontario transit properties. Terms and conditions have not been discussed and the feasibility of this alternative requires further investigation.

7.12/ Mobile Data International, Motorola (MDI)

Motorola has a strong presence in the North American transit AVLC marketplace, in terms of radio and base-station communications and signpost technology. Recently purchased, MDI (a division of Motorola Canada) is now the conduit through which Motorola will be pursuing any AVLC projects in Canada.

MDI is now in a position to use the Motorola name to offer its services as a prime contractor in providing turnkey transit AVLC systems. While fully capable of providing any low-level software needs (e.g., software for programmable in-vehicle control units), presently MDI has no plans to develop any central site software.

On the BC Transit project, MDI has teamed up with Teleride-Sage Limited (TSL) to develop and install a two-way data and voice radio trunk system which will automatically select and assign radio channels as required. Tied into a central computer, the system will be able to interface with other onboard systems such as Automatic Vehicle Location (AVL), Automatic Passenger Counting (APC), and Electronic Farebox (EFB) systems. TSL is providing the application software for the dispatch office including the handling and queuing of all incoming messages.

In terms of other future AVLC projects, MDI has indicated that they will be supplying Motorola signpost and remote terminal technology. Presently, there are no immediate plans for the development of a LORAN-C or GPS receiver product line.

7.13/ Mobile Electronics Tracking Systems (METS)

METS has developed TRAKMAP, an AVL and mapping program that tracks vehicles equipped with METS Vehicle Computer Units (VCU/TRACKER). The software provides local mapping and dispatch information for the entire transit fleet. The central software can be programmed to report on schedule adherence and off-route activity. The in-vehicle system uses a differential LORAN-C receiver for determining a vehicle's location. METS says its data control unit can also be interfaced with dead reckoning or GPS receiver technology.

METS considers itself a systems integrator, ready and willing to be the prime contractor in providing turnkey AVLC system solutions. While the full capability is not yet in place, METS is looking for one or more large development contracts to provide the funding for development of its planned product line that will leverage the company into a leadership role in the North American AVLC marketplace. The company's goal is to be able to provide a full turnkey off-the-shelf AVLC system solution to the transit marketplace by 1992.

7.14/ Navigation Data Systems (NDS)

NDS, formerly an ONI products division, has its roots firmly grounded in the LORAN-C marketplace. Its parent, ONI, is responsible for installing many of the LORAN-C transmission stations around the world, including coastal systems in the United States and other countries around the world. NDS specializes in AVL systems for terrestrial, marine, and air navigation.

The NDS Fleet Management System (Fleet-Trak) comes in a variety of flavours including: law enforcement, trucking, aviation, marine, transit, executive security, emergency medical services, and the military. The transit-based Fleet-Trak system offers schedule adherence monitoring, routing and scheduling software, and textual, graphical, and electronic map displays.

NDS believes it is capable of delivering complete turnkey transit AVLC solutions and would take a prime contractor's role when bidding on AVLC projects. While its obvious specialty is LORAN-C, it believes its Fleet-Trak system can operate using signpost, dead reckoning and GPS location technologies with a minimum of re-engineering and customization.

The NDS in-vehicle mobile unit is a mature and stable product and can be operated with or without a driver display console. The company's central software typically runs on a MicroVAX 3100 with one graphics terminal (capable of displaying maps) and one text terminal. The software also optionally provides for schedule adherence, vehicle maintenance monitoring, public information system interface, and a customer info centre. If only fleet tracking is required, a cheaper PC-based version can be used for fleets under 40 vehicles.

The approximate costs (in U.S. dollars) of a basic Fleet-Trak system configured for use in the transit industry are:

LORAN-C Receiver (odometer interface)	$ 1 700
Filter (per florescent light)	$ 60
Status Display (10 push button)	$ 700
First Base Station (h/w & s/w)	$45 000
Additional Workstations	$25 000
Communications Interface Equipment	$ 5 000

Fleet-Trak systems have recently been installed in Youngston, Ohio and Traverse City, Mighigan.

7.15/ Teleride-Sage Ltd. (TSL)

TSL is in the process of developing and improving its entire range of transit oriented application packages. The new software incorporates many features highlighted in this report, for example: modular approach, fourth-generation and C programming languages, and relational database management technology.

TSL's preferred application environment for running its applications is under Unix. The Unix operating system allows for multi-user applications and may run on any one of a number of competing computer manufacturers' hardware platforms. The company does, however, also provide applications for VAX/VMS and PC-DOS.

Recent project work by TSL includes the central software on the Baltimore MTA AVLC system and a team effort with Motorola to provide an integrated voice/data radio system for BC Transit. In terms of roles on AVLC projects, TSL offers both prime and sub-contractor services.

7.16/ Toronto Transit Commission (TTC)

TTC has implemented a signpost/odometer-based system which will eventually operate in eleven divisions in three districts throughout the greater Metropolitan Toronto service area. The onboard vehicle data control unit and driver control head were manufactured by Glenayre/RMS. Bell Radio Communications provided much of the data and voice communications interface and control equipment. The central software, including schematic route displays, schedule adherence and radio control was custom developed in-house by TTC.

TTC and MTO have recently been investigating the possibility of using the TTC central software for other Ontario properties. While the rights to use the software may come at no cost to Ontario properties, there would, however, be an additional cost associated with adapting or customizing the software for use at other properties.

7.17/ Trimble Navigation

Trimble is very much involved in the general AVLC and CAD marketplace. The company, through strategic alliances with Advanced Control Technology (ACT) and Planning Research Corporation (PLC), has the capability to deliver turnkey transit AVLC systems.

Trimble's vehicle tracking systems have base-station hardware complete with electronic mapping capability, UNIX-based open architecture to allow for integration with third-party hardware and software, and application development tools for

customization. The company's AVLC system, customized for transit, supports real-time schedule adherence and route monitoring.

On the vehicle, Trimble can supply a microprocessor-based logic unit, combined with its GPS receiver. The unit is capable of supporting other location technologies such as LORAN-C, signpost receivers, and dead-reckoning-based systems.

Trimble wants to become a major player in the transit AVLC marketplace. For this reason, the company will play the role of prime contractor on small- to medium-sized projects. On the larger projects (greater than $5 million U.S. dollars), Trimble will be a major sub-contractor, leaving the system's integration and project management to its much larger strategic partners (i.e., Westinghouse, IBM, Harris, Motorola).

The approximate cost (in U.S. dollars) of a Trimble logic unit, complete with control head, modem, and GPS receiver is $3100.

7.18/ Westinghouse

The Commercial Systems Division of Westinghouse, Electronic Systems Group, was the prime contractor on Baltimore MTA's AVLC project. While Westinghouse was ultimately responsible for integrating and delivering the turnkey system, the company worked with many sub-contractors including: TSL, Glenayre/RMS, METS, and Harris.

In the course of implementing Baltimore's AVLC system, Westinghouse has found areas of improvement in the system's architectural design. Baltimore's central computer was sized for tracking the 50-vehicle test fleet. However, significant load results have made expansion more difficult. The communication link is also heavily loaded just performing the polling of buses on a regular basis.

As a result, Westinghouse has shifted to placing more intelligence on the vehicle. In future AVLC implementations, the company will propose that vehicle tracking be done onboard and reporting be performed on a synchronous or exception basis. This distributed configuration is expected to reduce central site processing and communication channels requirements.

In September 1991, Westinghouse was contracted by the Regional Transportation District of Denver, Colorado to install and CAD/AVL bus radio communications system. The $10.4 million (U.S.) contract will include as upgraded communications system serving six counties, CAD functions at the fixed end and vehicle location and communication capabilities for 632 buses and 80 supervisory vehicles.

8/ CONCLUSIONS AND RECOMMENDATIONS

This section details the conclusions and recommendations drawn from this report. Additional input throughout the reporting process was provided by the *AVLC For Small Ontario Properties Steering Committee.*

8.1/ Provincial AVLC System Standardization

Conclusion
The present day technology exists to allow MTO to conduct AVLC demonstration projects at one or more Ontario transit properties.

Conclusion
The North American AVLC marketplace is presently in a state of flux. Clearly, there is a lack of industry standardization, cohesion, and leadership. Selection of a single AVLC system supplier for a demonstration project may prove difficult.

Conclusion
At this time, settling on a province-wide technical AVLC standard would be premature. (A parallel can be drawn between the level of standardization within the present AVLC industry and that of the personal computer marketplace prior to the introduction of the IBM Personal Computer in 1981.)

It is, however, feasible to produce a province-wide functional AVLC specification. The specification would address the user and system requirements as outlined in the body of this report. Although each transit property will have some unique requirements, the majority will require the same basic functionality regardless of the property's location or size.

Recommendation
A functional AVLC standard for the Province of Ontario should be developed. It should be used to form the basis for a Request For Information (RFI) or Request For Proposal (RFP).

Parallel to the above process, MTO should encourage provincial AVLC system standardization through the use of a Joint Procurement Strategy (JPS). The JPS would provide for the procurement of AVLC systems in volume at quantities of scale cost reductions. (System procurement would include hardware and software, maintenance agreements, and training.)

8.2/ Location System Technology

Conclusion
No one individual location technology is currently sufficient to meet all the tracking and accuracy requirements of a transit AVLC system. The means of locating a vehicle

must be determined by the intended application of the AVLC system to a given property's fleet (i.e., fixed route or demand responsive).

Conclusion
Presently, the best suited hybrid location systems for transit AVLC system applications appear to be:

- a signpost-based system with odometer/door opening sensors, employing map-matching software (fixed route only);
- a dead-reckoning-based system employing map-matching software (fixed route or demand responsive);
- a LORAN-based system with odometer/door opening sensors, employing map-matching software (fixed route or demand responsive);
- a GPS-based system with odometer/door opening sensors, employing map-matching software (fixed route or demand responsive).

Conclusion
Dead-reckoning-based systems may be enhanced with other location systems such as signposts, LORAN-C, and GPS, to eliminate the inherent problem of accumulated tracking errors (note that this method differs from using the dead-reckoning system as a backup to the radio location system).

Conclusion
A hybrid GPS/dead-reckoning-based location system is attractive due to its accuracy and coverage. This type of system will continue to be attractive for both fixed- and off-route vehicle tracking as the cost of GPS receivers continue to decline.

Conclusion
The limitations of a reverse approach system (e.g., a Teletrac or Quiktrak system) are the user fees resulting in larger long-term costs, lack of schedule adherence capabilities, and a lack of an interface to other transit system operational databases and application software.

8.3/ AVLC Related Computer Hardware and Software

Conclusion
The central site application software is an essential part of the overall AVLC system and may be implemented independent of the actual location technology used. The independence of the central software from the location system allows a location system to be changed or enhanced without a major impact on the existing software investment. Similarly, should a property wish to change or enhance its central

software, it can do so without directly impacting the existing location system technology.

Conclusion
The type of central site computer hardware will depend on the size of the transit property, the desired level of departmental automation, and the type of software applications required throughout the property. The computer hardware may consist of, and be configured as:

- a large central processor with multiple terminals,
- a network of workstations and/or personal computers,
- a combination of central processing, terminals and networked workstations and personal computers.

Conclusion
The core of a transit property's AVLC system is the associated database. This database should be relational. The organization of the database will be central or distributed depending on the property's computer hardware configuration and requirements. Portions of the system's database will be departmentally shared and portions will be private to one department or type of user, depending on the nature of the data being stored.

Conclusion
The AVLC system's controller or dispatcher station console screens may display any or all of the following: electronic map displays, graphical charts, schematic flow diagrams, and textual list and tables. The ability to use windowing technology, split screens, and multiple screens will depend on the type of computer hardware and software applications employed by the AVLC system.

Recommendation
As computer-based technology continues to be introduced into the transit marketplace, the individual transit properties should view their AVLC systems as a piece of the overall property-wide automation package.

8.4/ AVLC System Implementation Methodology

Conclusion
The degree of transit property-wide automation and the full integration of AVLC must be determined and resolved. The two current approaches to systems design are that AVLC systems may be implemented using either:

- a top-down approach where automation is implemented across the transit property first and then AVLC is added as a module; or

- a bottom-up approach where AVLC is implemented first, followed by other transit property departments being automated as required.

In either approach, all information or data elements to be stored and retrieved by the property-wide system must be identified first. This will permit the flow of compatible data elements between a property's various departmental systems.

Recommendation
Small- and medium-sized transit properties should not engage in custom development projects to implement their AVLC systems. The custom approach is expensive and time-consuming and most smaller properties do not have the in-house experience available.

8.5/ Transit Property Operational and Organizational Impact

Conclusion
The roles of the various transit property organizations and departments will be impacted by the introduction of AVLC. The roles of the central site controllers and dispatchers and the role of the on-street inspector may change dramatically. Both the extent of this change, and the determination as to which individuals have the ultimate authority over the real-time level of on-street service will be the responsibility of each property's *senior* management *prior* to AVLC implementation.

Conclusion
The major challenge for Ontario transit properties in the 1990s will increasingly focus on the training and motivation of their employees as these new innovations are integrated into the transit industry.

It is essential that senior management involve the system's end users in the design, development, and implementation process. It is essential that the AVLC system be accepted as a tool to assist in the job of controlling the fleet and not merely a replacement of existing staff and their abilities.

Recommendation
MTO should continue work with Ontario properties to study the control strategies and methods used by Ontario transit properties to monitor and control their fleets. The intent is to provide more information on which types of displays and data elements are most effective in different real-time circumstances and scenarios.

8.6/ Grouping Ontario Properties Based on AVLC Requirements

Conclusion
With respect to AVLC, Ontario transit properties can be viewed as belonging to one of two categories:

Full AVLC – this group is comprised of those properties ready to implement a full-scale AVLC system. Some main features of the AVLC system would include: schedule adherence, off-route monitoring, and on-line real-time and off-line historical data storage and retrieval.

AVL Only – this group consists of those properties requiring only a vehicle tracking (AVL) system with no schedule adherence. The system would provide vehicle location and tracking only. This type of system appears adequate for small properties and paratransit operations.

Recommendation
MTO, CUTA, and the AVLC Steering Committee should encourage the formation of an Ontario Transit Automation, Innovation, and Technology (OTAIT) user's group. The group should be open to all transit properties in Ontario. The user's group should provide an open forum for the exchange of information and expertise on automation and technology (including AVLC) presently in use or available for use at Ontario properties.

8.7/ Additional Recommendations

Recommendation
Although not largely highlighted in this report, transit properties should be considering tying their paratransit operation into the AVLC system. AVLC positioning information should be fed directly into a paratransit scheduling and dispatching system.

Recommendation
In conjunction with the AVLC demonstration projects, MTO should implement a study to attempt to quantify the before-and-after affects of AVLC on the demonstration properties.

Recommendation
Executive Information Systems (EIS) provide senior management with timely property-wide information. These types of systems could greatly enhance the role and awareness of senior management in the day-to-day operations of their fleets by placing practical information on their desktops. Therefore, the Centre for Transit Improvement (CTI) should be given the responsibility of creating a project to implement an Executive Information System (EIS) user's group for Ontario properties, develop a set of user requirements, and implement a demonstration project.

APPENDIX A/ List of Transit Systems in Ontario

MUNICIPALITY	STATUS	POPULATION	FIXED FLEET	DEMAND FLEET	FIXED ROUTE OPERATOR	CONTACT
Ajax	Town	47,000	15	6	Charterways	416-427-5713
Aurora	Town	18,000	3	-	Laidlaw Transit	416-727-1375
Barrie	City	54,000	19	5	Laidlaw Transit	416-726-4242
Belleville	City	35,479	15	2	Belleville Transit	613-962-1925
Brampton (Peel)	City	218,000	81	25	Brampton Transit	416-453-1741
Brantford (Paris)	City	78,453	25	6(+2)	Brantford Transit	519-573-7391
Brockville	City	20,760	3	1	Brockville Transit	613-342-8772
Burlington	City	115,000	34	7	Burlington Transit	416-335-7797
Cambridge	City	80,500	25	3	Cambridge Transit	519-623-1340
Chatham	City	42,000	13	1	Chatham Coach Lines	519-436-3224
Cobourg	Town	13,291	1	2	Charterways	416-372-4555
Collingwood	Town	11,500	3	1	Town of Collingwood	705-445-1290
Cornwall	City	46,000	29	3	Cornwall Transit	613-932-6252
Dryden	Town	6,200	3	1	Town of Dryden	807-223-2367
Elliot Lake	Town	16,500	3	1	Town of Elliot Lake	705-461-7203
Ernestown	Township	7,100	1	-	Town of Ernestown	613-386-7351
Fort Erie	Town	15,000	1	-	Dunn The Mover Ltd.	416-871-1600
Fort Frances	Town	8,600	3	1	Fort Frances Transit	807-274-9893
Guelph	City	85,000	32	7	City of Guelph	519-822-1811
Hamilton-Wentworth	Region	394,000	250	71	Hamilton Street Railway	416-528-4200
Hanover	Region	50,000	-	9	(non-profit organization)	519-881-2504
Kenora	Town	12,547	5	1	Excel Coach Lines	807-468-8906
Kingston	Region	91,182	49	17	Kingston & Laidlaw Transit	613-546-1181
Kirkland Lake	Town	13,000	2	-	McLellan Transportation	705-567-9361
Kitchener (Waterloo)	City	232,700	103	12	Kitchener transit	519-741-2567
Leamington	Town	12,830	3	1	C. A. Bailey Ltd.	519-326-5761
Lindsay	Town	15,265	5	2	Town of Lindsay	705-324-6171
London	City	292,000	178	17	London Transit	519-451-1340
Markham	Town	135,837	37	5	Miller Transit & TTC	416-475-4888
Midland	Town	12,100	2	-	Penetang-Midland Lines	705-526-4275
Milton	Town	25,000	4	1	(private operator)	416-878-7211
Mississauga	City	423,320	244	-	Mississauga Transit	416-279-5900
Newmarket	Town	40,000	9	4	Laidlaw Transit	416-895-5193
Niagara Falls	City	71,200	21	3	Niagara Transit	416-356-1179
North Bay	City	52,000	30	4	City of North Bay	705-474-0400
Oakville	Town	106,000	48	5	Oakville Transit	416-844-0881
Orillia	City	24,000	6	1	Penetang-Midland Coach	705-325-1311
Oshawa	City	127,479	44	8	Oshawa Transit	416-723-4623
Ottawa-Carleton	Region	568,252	817	82	O.C. Transpo	613-741-6440
Owen Sound (Derby)	City	20,500	6	1	Laidlaw Transit	519-376-1440
Pembroke	City	13,900	3	2	City of Pembroke	613-735-3675
Peterborough	City	62,000	32	5	Peterborough Transit	705-748-8895
Pickering	Town	55,000	18	See Ajax	Pickering Transit	416-683-1179
Port Hope	Town	10,462	3	1	Town of Port Hope	416-885-4544
Richmond Hill	Town	66,000	20	2	Richmond Hill Transit	416-737-4150
St. Catharines	City	140,000	52	5	St. Catharines Transit	416-685-4228
St. Thomas	City	29,000	7	-	Lewis Bus Line Ltd.	519-631-1680
Sarnia (Clearwater)	City	66,667	25	3	Sarnia Transit	519-336-3271
Sault Ste. Marie	City	72,800	31	6	Sault Ste. Marie Transit	705-759-5438
Stratford	City	26,625	17	3	Stratford Transit	519-271-4700
Sudbury	City	98,869	47	6	Sudbury Transit	705-674-3141
Thunder Bay	City	112,000	61	13	Thunder Bay Transit	807-625-2188
Timmins	City	45,500	25	3	Timmins Transit	705-264-1331
Toronto (metro)	Region	2,133,400	2,783	175	Toronto Transit (TTC)	416-393-3658
Vaughan	Town	76,900	24	2	Vaughan Transit	416-832-2281
Walden	Town	8,000	3	-	Bill Martin Bus Lines	705-866-2862
Welland	City	43,500	14	2	Welland Transit	416-732-6844
Whitby	Town	49,000	14	3	Charterways Transportation	416-668-5803
Windsor	City	195,000	106	12	Windsor Transit	519-944-4111
Woodstock	City	27,000	12	2	Woodstock Transit	519-539-1291

** NOTE: Information and statistics as of 1989

APPENDIX B/ AVLC Radio Specifications

Below is a list of some suggested specifications for a two-way data/voice radio system supporting a polling/data-and-voice-type AVLC system. The specifications have been provided for this report courtesy of Bell Radio Communications Inc. Actual AVLC radio systems do *not* necessarily have to meet all these specification exactly. The specifications provide guidelines to the type of technical information a transit property should be aware of before tendering for a system. The specifications are for a conventional (non-trucking) mobile radio system.

Military Specifications Standard 810D
MIL-810D specification standards are designed to meet the challenge of operating under the harsh transit environment conditions. These are guidelines only. The cost of a radio which would actually meet all of these specifications would be prohibitively high for most transit properties.

a) Low Temperature	–	method 502.1, procedure 1
b) High Temperature	–	method 501.1, procedure 1
c) Vibration	–	method 514.2, procedure 8
d) Shock	–	method 516.2, procedure 1
e) Humidity	–	method 507.1, procedure 2
f) Rain	–	method 506.1, procedure 1
g) Dust	–	method 510.1, procedure 1
h) Salt Fog	–	method 509.1, procedure 1

Department of Communications RSS-119 Test Procedure
DOC RSS-119 TP is for data and voice modulation of radio-telephones and forms the absolute minimum requirements for data and voice communications. The radio parameters in this specification are important because they may constrain the upper performance limits of a data system. Meeting this specification will make radio systems *more* costly.

Transmitter Attack Time – 20 Milliseconds or as required
This specification is significant with the use of higher baud rates. If the Transmitter Attack Time is too long it can negatively impact the bandwidth efficiency of the data communication system.

Channel Switching Time – 20 Milliseconds or as required
If it is too long, this parameter may also negatively impact the data bandwidth of the system by imposing wait states in the message transmission.

Receiver Attack Time minus Transmitter Attack Time
This is a relevant performance factor only if the Receiver Attack Time exceeds the Transmitter Attack Time.

Support CTCSS Modules
Used for normal and fallback mode voice (selective) communications.

The Channel Select Interface (CSI) – may be serial or parallel. Including specifications for a parallel CSI may avoid additional engineering costs for the conformance to proprietary based system interfaces, but may tend to exclude other appropriate and less costly serial-based products.

Transmit Signal to Noise Ratio (snr) >= 42 db
This factor effects the success rate of data message throughput.

Table C-1/ Existing AVLC Systems: Property Data

Transit Property Name	City (Prov/State)	Phone	Contact
Ann Arbor Transportation Authority (AATA)	Ann Arbor (MICHIGAN)	313-973-6500	M. Bolton
Calgary Transit	Calgary (ALBERTA)	403-277-9716	F. Wong
Champaign-Urbana Mass Transit District	Urbana (ILLINOIS)	217-384-8188	N/A
Dallas Area Rapid Transit (DART)	Dallas (TEXAS)	214-828-6779	Mr. Dobbin
City Transit Service of Fort Worth (CITRAN)	Forth Worth (TEXAS)	817-871-6232	Mr. Buckley
Hamilton Street Railway Company (HSR)	Hamilton (ONTARIO)	416-527-4441	P. MacNeil
Hillsboro Area Regional Transit Authority	Tampa Bay (FLORIDA)	813-623-5835	S. Roberts
Kansas City Area Transportation Authority (KCATA)	Kansas City (MISSOURI)	816-346-0233	J. Dobies
Mass Transit Administration of Maryland (MTA)	Baltimore (MARYLAND)	303-333-4088	V. Roa
Metro Transit, City of Halifax (METRO)	Halifax (NOVA SCOTIA)	902-421-6619	H. Mombourquette
Metro Transit Authority of Harris County (METRO)	Houston (TEXAS)	713-739-6013	B. Kronenberger
New Jersey Transit – Bus Operations (NJT)	Newark (NEW JERSEY)	201-378-6513	M. Revis
Ottawa-Carleton Regional Transit Commission (OC TRANSPO)	Ottawa (ONTARIO)	613-741-6440	M. Bellinger
Sheboygan Transit System	Sheboygan (WISCONSON)	414-459-3281	N/A
Société de Transport de L'Outaouais (STO)	Hull (QUEBEC)	819-776-6934	R. Lessard
Tidewater Regional Transit (TRT)	Norfolk (VIRGINIA)	804-627-9291	J. Whitney R. McFarlan
Toronto Transit Commission (TTC)	Toronto (ONTARIO)	416-393-3600	W. Frost
VIA Metropolitan Transit (VIA)	San Antonio (TEXAS)	512-227-5371	W. Hayle J. Pheil

N/A – not available

Table C-2/ Existing AVLC Systems: Systems Data

Property	*FLT/ RTE	AVL	Prime Contractor	Accuracy	**SA	Comments
AATA	65/22	DR	GRS	±20m	Y	ETAK display and map-matching
Calgary	504/100	SO	PLD Systems	± 10 sec	Y	25 buses equipped, 60 signposts plus 6 portable beacons
Urbana	69/10	L	II Morrow	±60 m	Y	AVL system expansion halted, EIS
DART	750/100+	SO	Motorola	±60 m	Y	
CITRAN	150/35	SO	F & M Global	N/A	Y	
HSR	284/37	SO	primed in-house	±30 m	Y	60 beacons
Hillsboro	182/47	SO	Motorola	±100 m	Y	80 beacons (full implementation expected February 1992)
KCATA	260/35	SO	F & M Global	± 120 m, urban ± 200 m, rural	Y	95% within 15 seconds, system now complete
MTA	900/70	LO	Westinghouse	±75 m	Y	50 buses for test (two1/2 mile dead zones)
Halifax	170/41	SO	Gandalf	±180 m	Y	32 beacons, GOTIME system
Harris	1000/100	RS	Amtec	± ??	N/A	99.9% read at 75 mph (prototype/demonstration stage)
NJT	1900/200	SO	Motorola	±15 m	Y	600 beacons state-wide, implementation expected Spring 1991
OC Transpo	800/130	RS	Amtec	± ??	Y	6 readers on Transitway (prototype demonstration stage)
Sheboygan	34/12	L	II Morrow	±60 m	N	manual schedule adherence
STO	173/65	SO	F & M Global	±60 m	Y	19 beacons, INFOBUS system
TRT	140/40	SO	F & M Global	±60 m	Y	80 beacons, 95% within 15 seconds
TTC	2000/138	SO	primed in-house	±15 m	Y	650 beacons
VIA	540/90	SO	GRS	±90 m	Y	220 beacons, onboard monitoring of door-opensings, 95% within 15 seconds

KEY: DR = Dead Reckoning
R = Reverse Signpost
G = GPS
SO = Signpost/Odometer
L = LORAN-C
LO = LORAN/Odometer

*FLT/RTE = Fleet Size/Number of Routes (fixed route fleet)

**SA = Schedule Adherence Monitoring

Table D-1/ Vendor Update Summary

Vendor	Product	Prime	Sub	Off The Shelf	Schedule Adherence	Contact
BRC	Communications, Systems Integration	•		No	N/A	T. Charron (416)890-0000
ETAK	Navigation, Mapping, Dead Reckoning		•	Yes	Nois	A. Pitcairn (415)328-3825
F & M	Location, In-vehicle Hardware, Comms Control		•	No	No	K. Peck (214)241-4242
GMSI	Hardware, Firmware, Comms Control	•	•	No	No	J. Seymour (613)723-6500
GRS	TransitMaster (discontinued), Electronic Tag Systems	•	•	Yes	Yes	L. Fiest (716)783-2107
Glenayre/RMS	In-vehicle Hardware, Comms Control, Software	•	•	Yes	Yes	G. Jonsson (604)293-4379
Il Morrow	AVL System Hardware, Software, LORAN-C Receiv ers		•	Yes	No	L Courtland (503)581-8101
LocUS	LORAN-C Receivers (GPS Receivers)		•	No	N/A	L. Roth (608)244-0500
Magnavox	GPS Receivers, Dead Reckoning Systems		•	Yes	N/A	C. Wohl (310)618-7319
Marcor	GPS Receivers (Systems Integrator)	•	•	No	N/A	W. Armstrong (202)408-0080
Halifax	GOTIME Software			Yes/No	Yes	B. Smith (902)421-6600
MDI	Signposts, Mobile Radio Communications, Mobile Terminals	•	•	No	N/A	R. Vanstone (416)499-1441
Mets	Hardware, Software, Mapping, LORAN-C/GPS Receivers	•	•	Yes	Yes	J. Russell (317)573-2200
NDS	Hardware, Software, LORAN-C/GPS Receivers	•	•	Yes	Yes	C. Crowder (504)734-5566
TSL	Transit Software and Systems	•	•	Yes	Yes	R. Clarke (416)596-1940
TTC	CIS Software			Yes/No	Yes	W. Frost (416)393-3600
Trimble	AVLC Hardware, Firmware, GPS Receivers	•	•	Yes	N/A	G. Gross (408)730-2900
Westinghouse	Systems Integrator (Software)	•	•	Yes	Yes	C. Body (301)765-8329

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